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# Effective Use of Oxy-Fuel Combustion in Aluminum Reverberatory Furnaces

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## Introduction

Reverberatory (reverb) and rotary furnaces are widely used for recycling non-ferrous metals such as aluminum. In any furnace, heat transfer from the flame to the melt charge can occur in two ways: directly from the flame to the charge and indirectly from the flame to the refractory walls of the furnace, and then from refractory walls to the charge.

In a rotary furnace, the rotation enables the hot refractory to pass under the metal charge, thus transferring heat more effectively from refractory to metal. As such, rotary furnaces have very high efficiencies (or "furnace factors") of up to ~90% (where furnace factor is defined as the percentage of available heat absorbed by the charge material[1]). This high efficiency naturally fits the use of oxy-fuel combustion because the higher available energy from oxy-fuel combustion can be more efficiently transferred to the melt in a rotary furnace.

In contrast, reverb furnaces are stationary and relatively larger in volume, with burners typically mounted horizontally. Heat transfer from the flame to the melt is limited, with lower furnace factors of around 65% typically achievable.[1] Use of conventional oxy-fuel burners with higher available energy and heat flux is more difficult in these furnaces if heat cannot be transferred to the melt effectively. Conventional oxy-fuel burners may pose the following challenges in reverb furnaces:

- Localized overheating due to higher radiation from oxy-fuel burners, especially to the roof
- Non-uniform heat distribution in the furnace due to lack of convection with reduced flue gas volumes and poor furnace pressure control
- Quicker cut back in firing rate of oxy-fuel burners due to control thermocouple temperatures reaching set point too quickly from higher radiation
- Yield losses due to non-uniform heat and oxygen distribution close to the metal
- Higher $NO_x$ due to interaction of the oxy-fuel flame with leakage air from the atmosphere or with the air-fuel flame in oxy-fuel boost cases, where the flame interaction is not controlled.

The Transient Heating burner (THB)[2] was specifically developed to address these challenges and make the use of efficient oxy-fuel combustion more amenable to reverb furnaces. It employs the direct flame impingement (DFI) mode to improve convective heat transfer from oxy-fuel combustion to the melt,[3] thus improving the efficiency or "furnace factor" of the reverb furnace. DFI mode is one of the most efficient modes of heat transfer and is well documented in literature.

This article presents the key attributes of the THB technology and how it addresses specific challenges associated with the use of conventional oxy-fuel burners in reverb furnaces. Data from laboratory tests are presented to highlight the features of the burner. Data from field installations are also presented to highlight the benefits achieved by the technology in practice.

## THB Technology

The THB is usually mounted on the furnace roof and typically has four nozzles directed toward four quadrants of the furnace below the burner. Using proprietary control techniques, the burner can direct heat to any combination of the quadrants using temperature feedback or timed firing. In this way, the burner delivers all the efficiency benefits of DFI, while avoiding overheating by limiting the firing in any one direction. In Figure 1, a conventional oxy-fuel burner (top) is shown firing in a horizontal orientation, delivering heat mainly via radiation. Meanwhile, the roof-mounted THB (bottom) is shown firing vertically, delivering heat via both radiation and convection (direct flame impingement).

It is well known that if pure oxygen or enriched air is used as an oxidizer in the flame, the heat transfer rate from the flame to the target it is impinging on can be significantly enhanced. Heat transfer rates up to ~2 $MW/m^2$ have been reported in lab-scale studies with oxygen natural gas flames operating in DFI mode.[4] However, this mode can present significant drawbacks if used improperly. If flames are continuously directed onto the melt at one spot, they can lead to localized overheating, potential refractory damage, and oxidation of the metal (yield loss) due to interaction with an oxidizer.

The photos in Figure 2 show the THB burner directing heat in each of four different directions. It can be controlled automatically or via operator experience. The technology enables modulation of flame length and momentum to provide improved melting, while minimizing oxidative melt losses by creating a reduc-

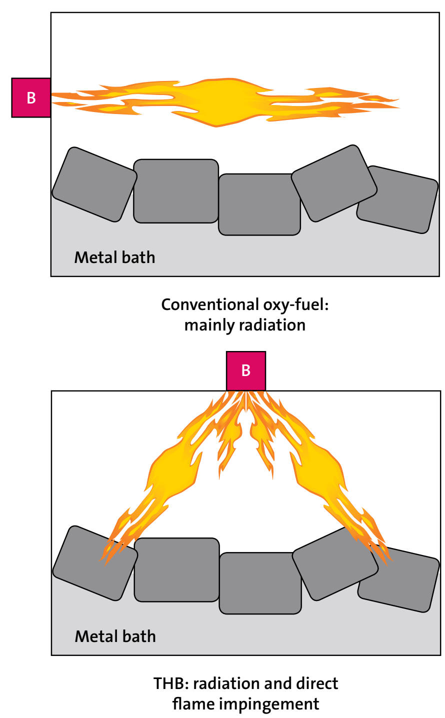


Figure 1. Modes of heat transfer: conventional oxy-fuel (top) and THB (bottom).

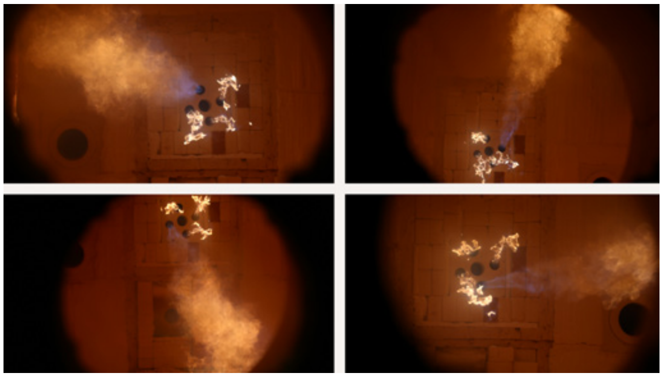

Figure 2. THB transferring heat in each of four different directions.

ing atmosphere near the melt. The burner can also be operated with one, two, three, or all four nozzles activated at the same time depending on the required heat distribution and flame length.

**Preventing Overheating and Non-Uniform Temperature Distribution**: The THB achieves uniform temperature distribution through the generation of vortices by selectively modulating multiple flames, which delivers heat to where it is needed in the furnace. Heat flux from the burner is directed to a certain zone and then moved to a different zone, avoiding overheating and allowing heat to soak in. Temperature measurements from thermocouples and other sensors can be used to determine where heat is needed.

Figure 3 shows the effectiveness of this control system in a large test furnace during a heat-up cycle. During the initial heat-up (conventional heat-up), the THB was operated with all four nozzles firing equally, and there was a significant difference in the temperature of the furnace at different locations. During the second phase (transient heat-up), the transient heating mode of the burner was turned on, using the thermocouple signals to direct more heat to the cooler areas of the furnace and less to the hotter areas. The rapid convergence of the furnace temperature readings can be clearly seen (heat-up curves coming together). In the third mode (setpoint control), the burner is controlling the temperature in different parts of the furnace at the same setpoint. In this mode, the burner can be programed to control the total energy input in addition to the distribution of energy in the furnace. This ability to uniformly maintain the temperature in the furnace is important for soaking/holding furnaces that hold molten aluminum prior to casting.

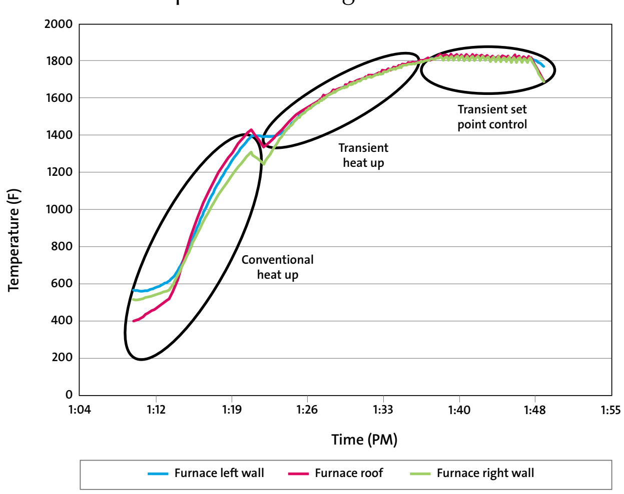


Figure 3. Uniform temperature control in the furnace using the THB.

With its ability to move the heat distribution in the furnace, the THB can easily adapt to variations in charging practices and minimize cold spots in the furnace. When mounted in the roof, the burner directs most of the heat downward, avoiding overheating of the roof and false triggering of the furnace control thermocouple. Thus, the burner can more evenly distribute the high available energy from oxy-fuel combustion in the furnace with improved efficiency while avoiding hot spots.

**Preventing Oxidation and Melt Loss**: The THB is specifically designed to create a reducing atmosphere near the melt. The high momentum flames directed to the melt in the DFI mode are rich in CO when they interact with the melt. Thus, in a roof-mounted version, most of the oxygen remains near the roof and is carried in by the natural gas to complete combustion. In addition, yield losses are minimized, as the oxygen is consumed before contacting the aluminum melt.

**Minimizing $NO_x$ Generation**: In an ideal scenario with oxy-fuel combustion, $NO_x$ is not generated due to the lack of nitrogen in the furnace atmosphere. However, most furnaces are not airtight and are often run close to neutral pressure. This can lead to stray (ambient) air entering the furnace and interacting with the oxy-fuel flame to generate $NO_x$.[5] The THB creates spatial and temporal striations of reducing and oxidizing atmospheres in the furnace, which reduces flame temperature. Additionally, CO is constantly created and destroyed in different parts of the furnace, leading to $NO_x$ suppression. This inherent preferential operation of the burner results in low $NO_x$ generation. Figure 4 compares the low $NO_x$ generated by the THB with conventional oxy-fuel burners as a function of air leakage (percent of total flue gas volume) into the furnace. Similar behavior would be expected in the case where the THB is used in a boost capacity to supplement existing air-fuel burners.

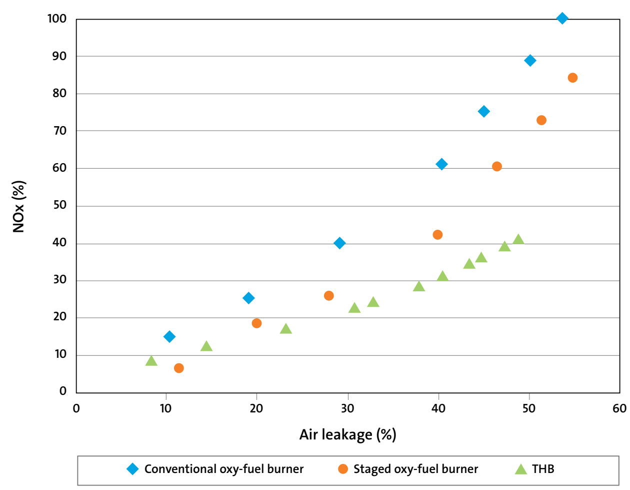


Figure 4. NOx characteristics of the THB compared to conventional and staged oxy-fuel burners.

**Boosting Air-Fuel Operations**: Typically, reverb furnaces are equipped with air-fuel burners mounted on the sidewalls, which fire along the length of the furnace. These burners can be cold air, recuperative, or regenerative (regen) types. Use of regenerative (regen) burners is common. Regen burners work in pairs, with 80% of the flue gases exhausting through the burners for heat recovery. Often, the designed flows through the regenerative bed deteriorate with time, requiring constant maintenance and costly reductions in furnace performance. This "pitching and catching" operation often leaves parts of the furnace cold. These colder areas can be boosted using oxy-fuel combustion. With improved efficiency over conventional oxy-fuel combustion, low $NO_x$, and ability to direct the flame in different directions, the THB is a good fit for boosting applications.[6] Moreover, operation of the THB can be tuned with regen burners such that the oxy-fuel flames do not interact with the regen flames (Figure 5), further reducing overheating and the potential for $NO_x$ generation.

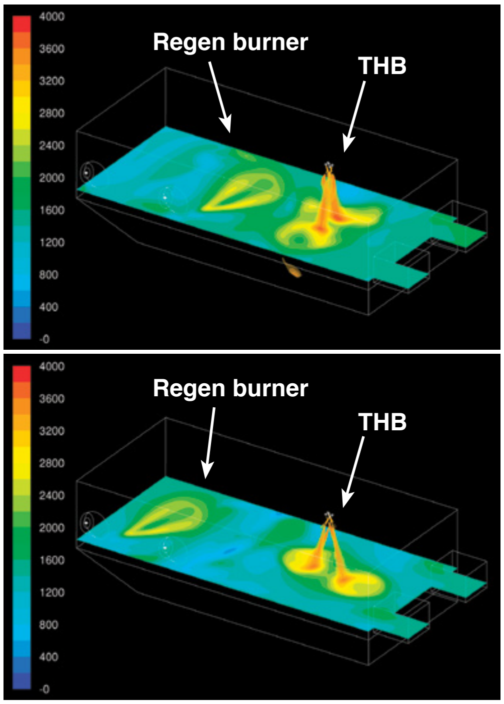


Figure 5. CFD model illustrating the THB switching operation in tune with regenerative burners.

**Enhancing Efficiency Using Sensor-Based Control Strategies**: Continuous monitoring of furnace, operation, process, and control data can be used in conjunction with the ability of the THB to control energy input and distribution to optimize furnace efficiency. In the case of melting, the control strategies can be used to calculate the energy required to completely melt the charge material and provide closed- or open-loop heat input control, with either automatic burner shutdown or automatic reporting for operators.

Machine learning technology allows the controls to continuously improve over time as more data is fed back into the model. Accurate end-of-melt prediction, combined with timely burner shutdown control, can provide significant benefits, including improved specific fuel consumption, reduction in cycle time, improved yield, and increased production. Other aspects of the strategies can lead to reduced furnace downtime with predictive maintenance, improved production planning, and precise cost/benefit analyses.

## Field Installations

Gangoli, et al., presented a theoretical efficiency comparison between different burner technologies for rotary and reverb furnaces.[1] The furnace factor for the THB was calculated to be 75% compared to 65.7% for a conventional oxy-fuel burner operating in the reverb furnace. The increase in furnace factor is because the THB utilizes direct flame impingement. Additionally, by using temperature sensors located in different parts of the furnace, efficiency can be further improved. Thus, additional fuel savings and production benefits can be realized by shifting the operation from air-fuel combustion to THB combustion.

THB was installed in an aluminum reverb furnace in Brazil. The customer achieved a 35% productivity boost, 48% reduction in fuel consumption, and 20% lower melt losses in the operation relative to baseline air-fuel operation. Minimal maintenance was required on the burner, with nozzles replaced once every year and the burner block replaced every two years.

In another installation for a reverb furnace in Asia, the THB achieved a 45% reduction in fuel consumption. Two THBs were installed to replace two air-fuel burners. This operation processes large quantities of flammable scrap, leading to volatile release during operation. As the flue gas volumes were reduced compared to base-line operation and the THB pushed the flammables down, the emissions from the furnace were greatly reduced during flammable scrap charging.

## Conclusion

Historically, there has been a reticence to use oxy-fuel combustion in reverb furnaces due to some unsuccessful early attempts and a mismatch between the oxy-fuel technology and needs of the melting operation. Oxy-fuel combustion technology has come a long way in the last 20 years, and its reliability has been greatly improved. With the advent of technologies like the THB, oxy-fuel combustion can provide benefits to reverb furnace operations that it has repeatedly demonstrated in very efficient and evenly heated rotary furnaces. For furnaces that have reached the maximum achievable production rate with air-fuel burners, the THB promises the ability to boost production. Furnaces specifically designed for oxy-fuel combustion (smaller volume and footprint) can further improve their efficiency and reduce capital costs. Coupled with sensor technologies and advanced process advising methodologies, capabilities of oxy-fuel technologies like the THB will be better leveraged to improve production rate and efficiency while minimizing emissions.

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