

# Oxy-Fuel Technologies and Strategies for Secondary Aluminum Melting Operations

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## Introduction

Secondary non-ferrous melting furnaces come in varied types, shapes, and sizes. A key variable in the melting rates of these furnaces is the furnace factor, which is defined as the percentage of total available energy (computed at a given flue gas temperature) that is actually absorbed by the metal during a melt cycle. The furnace factor is a function of furnace type, configuration (single/double pass), refractory type and thickness, number and location of burners relative to the product and flue duct, location and size of the flue duct, flue gas volumes, and residence times available for completion of heat transfer, etc. In simple words, it is a measure of the effectiveness of a furnace to transfer energy into the metal.

Melting furnaces utilize burners using air-fuel, oxy-fuel, or a combination of the two to provide heat. Oxy-fuel combustion is defined as the partial or full replacement of air-fuel with oxygen as the oxidizer in the combustion process. It has long been recognized for its high efficiency and high throughput melting characteristics.<sup>1</sup> By eliminating nitrogen from the process, oxy-fuel burners reduce the amount of heat lost via flue gases leaving the furnace. In other words, a higher percentage of the heat from the burner is available for melting.

The furnace factor in a rotary furnace is ~85-90%, as the rotation of the furnace enables the refractory to actively participate in heat transfer to the metal. Hence, the benefits from improvement in available energy by using oxygen to replace air as the oxidizer for combustion are almost fully utilized in a rotary furnace. For this reason, oxy-fuel combustion is a natural fit for—and widely implemented in—rotary furnaces. In comparison, stationary reverb furnaces are less efficient in transferring the total available energy to the metal (furnace factor ~50-65%) due to the lack of participation from the refractory in the form of convective heat transfer, radiation view-factors limited by bath surface area exposed to the incident energy, and inadequate uniformity of heat distribution/homogenization of the molten metal.

Table I and Figure 1 show a relative comparison of full oxy-fuel operation in rotary and reverb furnaces. In order to drive the same amount of energy into the melt

Description	Unit	Rotary	Reverb	Comments
Input Energy	MMBTU/hr	10.0	13.8	Higher energy input (38%)
Oxygen-in-Oxidizer	%	100	100	Full oxy-fuel operation
Available Energy	%	75.2	75.2	Assuming 2000°F flue gas
Furnace Factor	%	90	65.7	
Energy to Flue Gas	MMBTU/hr	2.5	3.4	
Energy to Product	MMBTU/hr	6.8	6.8	Same energy to product
Specific Fuel Consumption	BTU/lb	739	1012	
Specific Oxygen Consumption	SCF/lb	1.5	2.0	
Flue Gas Volume	SCF/hr	30,000	41,400	

Table I. Relative performance comparison of 100% oxy-fuel rotary and reverb furnaces.

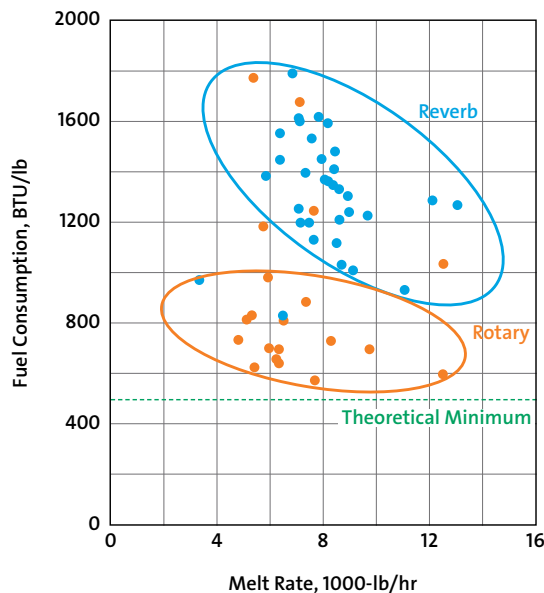


Figure 1. Fuel consumption vs. melt rates observed in rotary and reverb furnaces.

(6.8 million Btu/hr), a higher energy input of about 38% is required in a reverb (13.8 million Btu/hr) compared to a rotary (10 million Btu/hr) furnace. This article will examine the ways oxy-fuel technology can increase heat transfer in a reverb furnace, improving the furnace factor to be on par with a rotary furnace.

## Advanced Techniques to Improve Process Efficiency in Reverb Furnaces

The overall efficiency of energy transfer in a melting process is a combination of furnace factor and available energy. Available energy is defined as the portion of total energy that is not lost when the flue gases leave the furnace and, hence, is theoretically available to transfer to the metal. The energy lost by flue gases is a function of gas volume and temperature at which the flue gases exit the furnace. Oxy-fuel burners eliminate nitrogen from the process, reducing the amount of heat lost via flue gases, i.e., a higher percentage of the heat from the burner is available for melting (rather than being carried out with the nitrogen). Figure 2 shows how available energy varies with the percentage of oxygen-in-oxidizer (or oxygen-enrichment) used in the combustion process (where 20.9% = all air, 100% = all oxygen). As flue gas volumes drop, the available energy increases rapidly in conjunction with an increase in oxygen-in-oxidizer. The higher available energy inherent to oxy-fuel combustion is distributed between the metal and refractory rather than leaving the furnace through the flue.

A comparison of different combustion technologies in reverb furnaces is shown in Table II, with Case A representing air-fuel; Case B representing oxy-fuel; Case C representing the combination of air-fuel and oxy-fuel, referred to as air-oxy-fuel, in a specially designed burner; and Case D representing the combination of separate air-

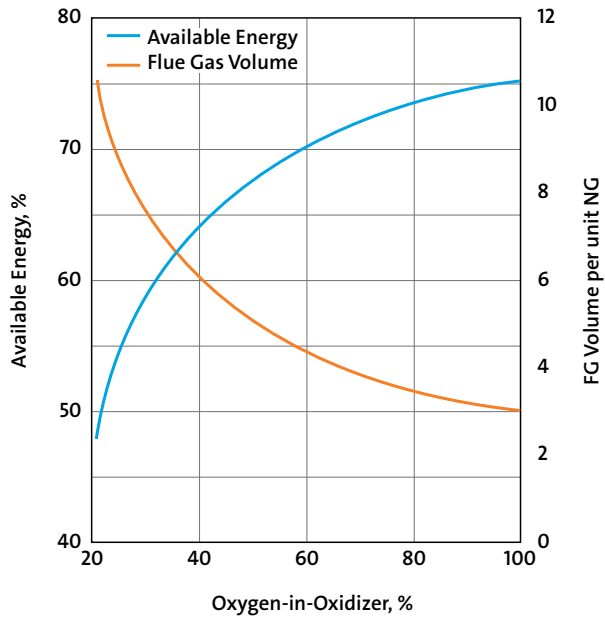


Figure 2. Available energy (flue gas temperature = 2,000°F) and flue gas volumes generated per unit of natural gas as a function of percentage oxygen-in-oxidizer (or oxygen-enrichment).

Description	Unit	AF	OF	AOF	Boost AOF
		25% Production Improvement			
		Case A	Case B	Case C	Case D
Input Energy	MMBTU/hr	26.4	17.2	22.2	30.4
Oxygen-in-Oxidizer	%	20.9	100	35	22.9
Available Energy	%	42.7	75.2	60.3	46.8
Furnace Factor	%	60	65.7	63.4	59.7
Energy to Flue Gas	MMBTU/hr	15.1	4.2	8.8	16.2
Energy to Product	MMBTU/hr	6.8	8.5	8.5	8.5
Specific Fuel Consumption	BTU/lb	1952	1010	1307	1788
Specific Oxygen Consumption	SCF/lb	0.0	2.0	1.3	0.5
Flue Gas Volume	SCF/hr	307,166	49,866	153,620	319,915

Table II. Comparison of air-fuel, oxy-fuel, and air-oxy-fuel in reverb furnaces.

fuel burners and oxy-fuel burners. Case A shows that air-fuel combustion in a reverb furnace requires 26.4 million Btu/hr to transfer 6.8 million Btu/hr of energy into the metal. Cases B-D reveal different options to increase the productivity of Case A by 25%. The full oxy-fuel version (Case B) uses less than two-thirds the amount of energy (17.2 million Btu/hr) and 84% lower flue gas volumes compared to Case A, with an oxygen consumption of 2 SCF/lb. Cases C and D use air-oxy-fuel combustion to achieve a 25% productivity improvement, while keeping the specific oxygen consumption lower than in Case B (0.5-1.3 SCF/lb). Cases B-D each enable a secondary melting operation to improve productivity of the existing furnace footprint with minimal capital investment (short payback), as well as achieve reduced costs. A deeper look at how secondary aluminum operations can boost productivity in reverb furnaces is described hereafter.

**Addition of Oxy-Fuel Burners:** In an operation constrained by its existing furnace footprint, an oxy-fuel boost can be applied. This involves the installation of appropriately sized and strategically located oxy-fuel burners, which work in tandem with the existing air-fuel burners. In this approach, the energy added by oxy-fuel burners accounts for only a portion of the total energy input into the fur-

nace. Case D in Table II presents an example operation, in which adding oxy-fuel burners that fire at 4.0 million Btu/hr (13% of total energy input) to a furnace along with the cold air-fuel burners firing at 26.4 million Btu/hr (as in Case A baseline) can improve productivity by 25%. This is a cost-effective method to improve productivity with moderate equipment investment and relatively quick return (<3 months). It is usually accompanied by marginally higher flue gas volumes (4%) and higher energy fluxes directed to the refractory in the furnace (27%). Computational fluid dynamic modeling is used to determine the optimal location of burners and analyze any interaction between flames. Energy input and distribution control strategies are critical to the success of such an installation.

Sapa Extrusions, Inc. implemented an oxy-fuel boost system on an aluminum reverb furnace using an Adjustable Heat Release oxy-fuel burner. A productivity boost of 15% was achieved in the operation after oxy-fuel boost burners were added to an existing regenerative air-fuel fired furnace.<sup>2</sup>

**Constant Air-Oxy-Fuel Operation:** One of the first reverb furnaces converted to oxygen-assisted melting was at Roth Brothers (later Wabash Alloys) in East Syracuse, NY. A cold air-fired aluminum sidewall furnace was retrofitted with EZFire LN air-oxy-fuel burners to increase production and reduce fuel usage. In both air-fuel and air-oxy-fuel modes, the furnace utilized a mechanical pump to assist the melting cycle by homogenizing molten metal temperatures and by pumping molten metal through the well to accelerate the melting speed. The system was run at a fixed oxygen enrichment rate throughout the melt cycle. The daily production rate was increased by 35% (from 156,000 lbs/day to 210,000 lbs/day) and the fuel usage was reduced from over 2,000 BTU/lb to 1,250 BTU/lb.<sup>3-4</sup> The enrichment level (oxygen-in-oxidizer) used to achieve these results was 35%, and the specific oxygen consumption was 1.2 SCF-O<sub>2</sub>/lb aluminum. Flue gas temperatures were somewhat lower with the air-oxy-fuel operation, showing the improved furnace factor and increased efficiency of driving heat into the melt.

**Flexible Air-Oxy-Fuel Over the Full Operation:** A Tunable Enrichment burner is capable of tuning the amount of oxygen-to-oxidizer (oxygen enrichment) ratio in the burner. It can be employed such that it operates in the oxy-fuel mode (Case B) during melting (i.e., when its energy efficient properties are best utilized) and in the air-oxy-fuel (Case C) or air-fuel (Case A) mode during non-melting portions of the cycle. This control strategy helps maintain flue gas volumes and stabilizes the furnace pressure, while optimizing the overall usage of oxygen. This approach also imparts the operational flexibility to adapt to varying production demands, such as operating in full oxy-fuel mode during high demand and air-oxy-fuel or air-fuel mode when the demand is low. Constant furnace pressure is an added benefit of this approach.

**New Generation Oxy-Fuel Burner Technologies:** Conventional melting approaches rely heavily on radiation heat transfer through burners that generate a flame in the open space of the furnace. This approach limits production rates in reverb furnaces due to the lower furnace factor. A novel melting technology, the Transient Heating oxy-fuel burner,<sup>5-7</sup> was developed to direct and uniformly distribute energy to the metal/bath, which can significantly improve the furnace factor of the operation compared to conventional burner technologies.

Direct impingement of the flame onto a metal charge is the fastest and most effective form of heat transfer. However, care must be taken to avoid local overheating and oxidation. The Transient Heating burner is a smart

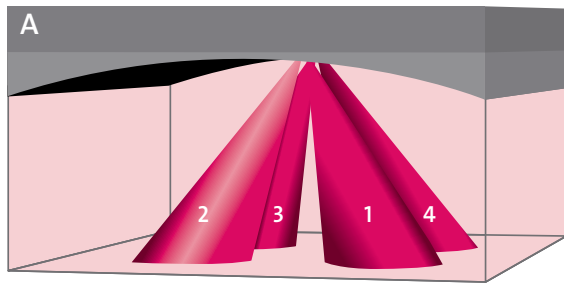


Figure 3. Implementation strategy for the Transient Heating burner.

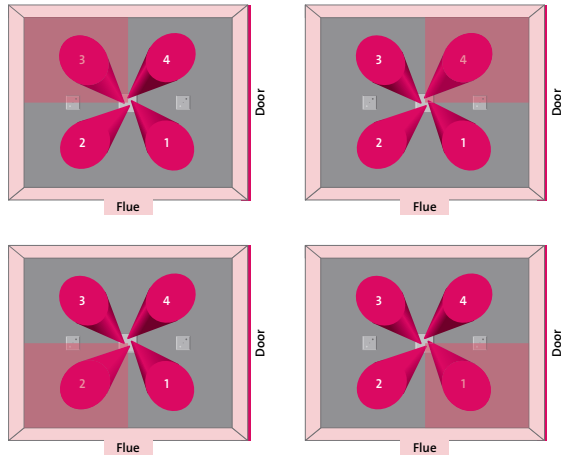


Figure 4. Furnace quadrants successively/cyclically heated by flames.

burner technology that uses a sensor-driven control strategy to maximize melt rates while delivering even heating throughout the furnace. The burner is installed on the roof (Figure 3) and configured to direct energy sequentially to the four different quadrants of the furnace. The quantity of energy and duration of time spent directing energy towards a given furnace quadrant can be preset to a given frequency or automated by strategically located sensors in the furnace (auto-pilot) to direct more heat to colder quadrants and less heat to hotter quadrants. Figure 4 shows the furnace quadrants successively heated in a cycle (1-2-3-4).

ALTREF installed a Transient Heating burner in an aluminum reverb furnace at its operation in Brazil. Figure 5 shows the burner heating two opposite quadrants simultaneously. ALTREF achieved a 35% productivity boost, 48% reduction in fuel consumption, and 20% lower melt losses in the operation relative to baseline air-fuel operation.

*Melt Stirring to Further Improve Furnace Factor:* Mechanical or electromagnetic molten metal pumps and inert gas stirring are commonly used to improve reverb furnace melt rates. These technologies can be used very effectively in conjunction with oxy-fuel combustion, because pumping the metal improves the furnace factor by increasing convection within the melt, transferring heat from hot areas of the furnace to colder areas, and speeding the transfer of heat from the metal surface to the bottom of the melt. In addition to improving heat transfer, inert gas stirring can provide additional benefits, such as degassing (potential elimination of a downstream operation step) and blanketing/inerting of the molten metal bath to prevent oxidation.

#### Comparison of Oxy-Fuel Technologies

As previously mentioned, the furnace factor in rotary furnaces is inherently higher (~85-90%) than that of



Figure 5. Photo of the Transient Heating burner operating in an aluminum reverb furnace.

Furnace	Description		Available Energy	Furnace Factor	Overall Efficiency	Estimated Specific Fuel Consumption
			%	%	%	Btu/lb
Rotary	Case 1A	Air-Fuel	42.7	83.3	35.6	1405
	Case 1B	Oxy-Fuel	75.2	90	67.7	740
Reverb	Case 2	Cold Air-Fuel	42.7	60	25.6	1952
	Case 3	Air-Oxy-Fuel or OF Boost	60.3	63.4	38.2	1307
	Case 4	Oxy-Fuel	75.2	65.7	49.4	1010
	Case 5	Transient Heating Oxy-Fuel	75.2	75	56.4	887
	Case 6	Transient Heating OF + Stirring	75.2	85	63.9	782

Table III. Summary of various options available to improve productivity and efficiency for rotary and reverb furnaces.

reverb furnaces (~50-65%). However, the proper implementation of oxy-fuel technologies has the potential to significantly improve the furnace factor for reverb furnaces. Table III compares the performance of oxy-fuel technologies in typical rotary (Case 1A-B) and reverb furnaces (Cases 2-6). As shown in Case 1b, a rotary furnace with 100% oxy-fuel has a high overall efficiency (67.7%), with a 90% furnace factor and 75.2% available energy. In comparison, a cold air-fuel fired reverb furnace (Case 2) has poor overall efficiency (25.6%), which comes from the combination of lower available energy (42.7%) and a poor furnace factor (60%). Furthermore, Cases 3 and 4 show how air-oxy-fuel and oxy-fuel combustion can be used in reverb furnaces to significantly improve the available energy and slightly improve the furnace factor by increasing radiant heat and residence time.

Cases 5 and 6 show the benefits of using the most advanced smart oxy-fuel technologies in reverb furnaces—such as the Transient Heating burner, which improves performance through both the advantages of oxy-fuel and by increasing the reverb's furnace factor to 75% via direct-flame impingement onto the metal charge. The heat transfer rates are much higher, while minimizing local overheating or oxidation of the melt using a proven sensor-driven control strategy to evenly distribute the energy in the furnace.<sup>5-7</sup> The furnace factor can be synergistically improved further to 85% by employing mechanical or gas stirring to improve the heat transfer within the metal bath and increase its ability to absorb heat (Case 6). Thus, a reverb fur-

nance using Transient Heating burner technology and molten metal stirring can achieve overall efficiencies of 63.9%, which approach those of a full oxy-fuel fired rotary furnace (67.7%).

In a low fuel price environment, it may seem less attractive to invest in advanced energy optimization techniques like partial or full oxy-fuel conversion combined with mechanical or gas stirring. However, the value of improved productivity (lower fixed cost per pound) for the same energy input/environmental footprint, lower flue gas volumes and dust carryover, and reduced time-at-temperature resulting in lower melt losses often lead to very short payback periods. It is common for a single furnace conversion to deliver over \$1 million per year of net benefit. The utilization of a Tunable Enrichment burner technology, which provides a relatively uniform energy distribution enabling the operation to fire harder and at higher oxygen-enrichment levels, also provides the flexibility to meet varying production demands and achieve better management of operating costs, thus facilitating an implementation strategy that can react to changing economic conditions.

### Conclusion

Oxy-fuel technology has been used principally in rotary furnaces for several decades due to the productivity and environmental benefits. The strong performance of oxy-fuel in rotaries is primarily the result of their high furnace factor. Reverb furnace operations have been slower to adopt oxy-fuel technologies because of their lower furnace factor. Transient Heating burner technology, along with stirring technologies, increase the furnace factor of reverb furnaces, allowing them to achieve

results of the same magnitude as rotary furnaces. Now reverb operators can enjoy the increased productivity, reduced energy consumption per lb, reduced emissions, and high metal yields that rotary operators have experienced for over 25 years.

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