Choosing the Right Technologies for Reverb Furnaces

Russell Hewertson,
Manager of Combustion Technology

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Introduction

Oxygen has been used for many decades to melt metals such as iron and copper, but only more recently for aluminum. Advances in burner design, flow control technology and operating experience have led to improved performance with faster melt times and lower costs in both reverb and rotary furnaces. Since 1989, Air Products has converted over 80 air-fuel fired aluminum reverb and rotary furnaces to oxy-fuel and air-oxy-fuel. For side-well furnaces, the best technology is often air-oxy-fuel because it matches the heat input to the customers operation—using oxygen when melting and air-fuel when holding, alloying and casting. For direct charge furnaces, oxy-fuel can often be the right fit to limit free oxygen in the furnace atmosphere, resulting in up to 2% yield improvements. Techniques for moving the flame have also contributed to efficient high yield melting, while flameless combustion burner designs can provide even heating throughout the furnace chamber with high convection heat transfer. This paper explains the potential advantages of oxygen in combustion for reverb furnaces, including lower total costs, higher production rates, better aluminum yield, increased flexibility of operation (where some furnaces can be shut down and production increased on others to minimize costs during downturns), lower fuel usage, and reduced flue gas volumes.

Oxygen in Combustion

Combustion is the chemical reaction between fuel and oxygen that leads to the generation of heat. Air contains 20.9% oxygen by volume, the rest being primarily nitrogen which is unchanged by the combustion process. When the oxygen concentration is raised above the normal 20.9%, the air is said to be oxygen-enriched. Increasing the oxygen content of air reduces the amount of inert nitrogen gas flowing through the combustion process, dramatically increasing the thermal efficiency. The impact of oxygen enrichment on flame temperature is well documented. Figure 1 shows the calculated adiabatic flame temperatures for stoichiometric combustion of natural gas with cold air containing varying concentrations of oxygen. The calculations show that the adiabatic flame temperature increases from 3550°F with air to over 5000°F with pure oxygen. Calculated adiabatic flame temperatures assume perfect mixing and no heat transfer which are not achieved in practice. Actual typical flame temperatures are about 3200°F for air-fuel and 4200° to 4500°F for oxy-fuel.

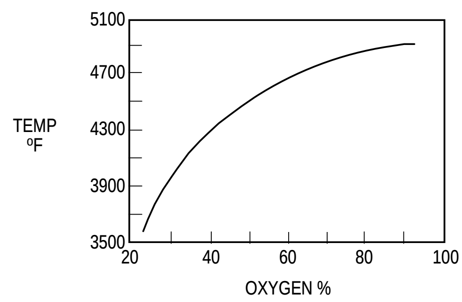

Figure 1: Effect of Oxygen Enrichment on Flame Temperature [1]

[1] C.E. Baukal, Ed., *Oxygen-Enhanced Combustion*. New York: CRC Press, 1998.

There are a variety of techniques for implementing oxygen enrichment. Oxygen may be mixed with the combustion air stream, injected through a lance near the flame, or through the use of burners designed specifically for high oxygen concentrations. The particular technique selected can have a significant impact on furnace operation and the magnitude of cost savings you can achieve. Plus, selecting a technique often depends upon the furnace type and size, operating benefits desired, and capital cost considerations. Installing burners that are designed to use oxygen instead of air generally results in the greatest operating cost savings.

The Original Technology: Air-oxy-fuel for Side-well Furnaces

The first successful application of oxygen in aluminum melting was on a rotary furnace. This application used a combination of air-fuel and oxy-fuel through Air Products' EZ-Fire™ air-oxy-fuel combustion technology, which was developed in the late 80's. The first commercial installation was in 1989 on a 25,000 pound single pass rotary furnace (Figure 2) and the system was later used on several reverb furnaces. EZ-Fire technology features the integration of an oxy-fuel burner with an air-fuel burner, providing the user with the flexibility to select the heat input from air-fuel and oxy-fuel independently. This way, the melt rate can be optimized to take into account constraints of the existing operation such as baghouse capacity and materials handling.

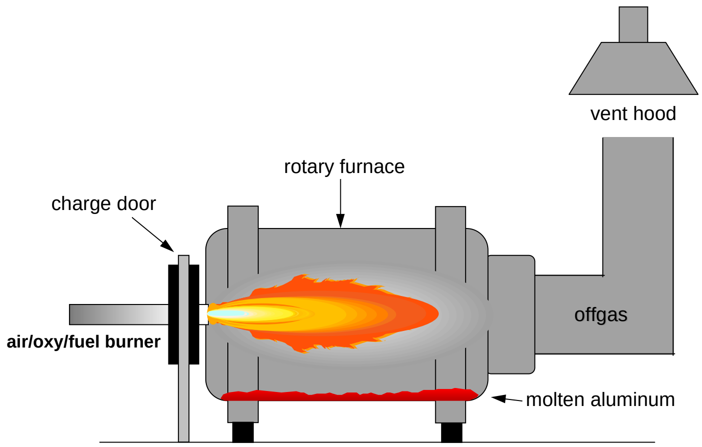

Figure 2: Air-Oxy-fuel Single Pass Rotary Furnace Retrofit

Most air-fuel combustion systems are compatible with EZ-Fire technology—a custom-designed oxy-fuel burner is inserted into the existing air-fuel burner. It can take 1 to 3 hours to retrofit a burner, and is usually done between heats. Ignition, flame supervision and cascading flow controls are integrated to provide a safe and efficient air-oxy-fuel combustion system. This burner-in-burner concept provides an air-fuel envelope around the hot oxy-fuel flame, protecting the burner tile and charge material from the hotter inner flame. The system has been used with both nozzle mix and pre-mix burners. New customers often use this methodology to evaluate oxy-fuel since it is a low risk way to witness the benefits, while keeping their existing flow controls intact.

With the EZ-Fire technology, heat input to the furnace can be varied between the air-fuel and oxy-fuel components, allowing moderation of flame temperature, adjustment of convective heat transfer characteristics, and a reduction in the volume of the products of combustion. This feature is particularly important where there are baghouse limitations caused by an undersized baghouse, excessive exhaust gas temperatures to the baghouse or a large number of fume collection hoods throughout the plant. By selecting less air-fuel and more oxy-fuel, the volume of hot exhaust gas going to the baghouse is reduced, which allows the baghouse to run cooler, use lower cost bags, and provide better suction at other locations inside the plant.

Overall, EZ-Fire technology can deliver operational improvements including production increases of over 30%, fuel savings of 20 - 30%, reduced emissions, lower baghouse temperatures (50-150°F) and reduced dust carryover (50%). Most existing reverb furnaces are designed for air-fuel firing and therefore have a large combustion space to allow for a significant volume for the combustion gases. Using 100% oxy-fuel significantly reduces the exhaust gas flows and can lead to uneven heating if adjustments are not made to control furnace pressure and gas residence time. Reverb furnaces have several functions and the quicker heat input of oxy-fuel is not always needed; such as holding, refining, and alloying. A typical reverb furnace operates in the melting mode for only 60-70% of the time. So, an air-oxy-fuel burner is often the best choice for reverb applications.

Another factor in matching the combustion technology to the furnace is the relationship between the oxygen enrichment level and available heat (see Figure 3.) Available heat is the energy which is "available" to be absorbed by the metal and excludes energy lost in the form of hot flue gases and other heat losses.

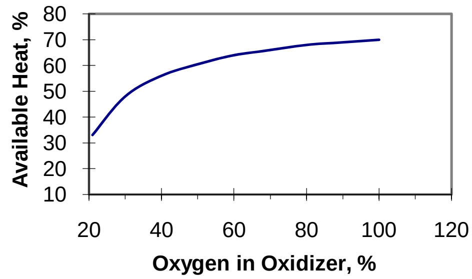

Figure 3: Available Heat vs. Oxidizer [1]

Starting with air at about 21% oxygen, each small addition of oxygen percentage corresponds to a significant increase in available heat. As you move up the curve to higher enrichment levels the relative improvement in available heat starts to flatten. For example, increasing the oxygen content from 21% to 40% increases the available heat from 33% to 56%, whereas increasing oxygen content from 50% to 100% only adds 9% of available heat.

The efficiency of heat transfer in a melting operation is dictated by the slowest or "rate determining" step. In effect, this step acts as the bottleneck, limiting the melt rate and production, regardless of the combustion system efficiency. In side-well reverb furnaces, the main mechanism of heat transfer is radiation, both from the flame and from the refractory. The rate determining step for side-well reverb furnaces is transferring heat from the melt surface into the bath and the material in the well. This limitation means there is often little advantage to using 100% oxy-fuel instead of air-oxy-fuel in side-well reverb furnaces. If the furnace uses a molten metal pump to mix the hot and cold metal it significantly improves the heat transfer within the melt and may give faster melt times with 100% oxy-fuel vs. air-oxy-fuel. If there is no metal pump, then air-oxy-fuel is often a better choice than 100% oxy-fuel. Other advantages of using air-oxy-fuel rather than 100% oxy-fuel (based both on results and extensive furnace modeling) may include: lower refractory temperatures; higher furnace pressure; even heating of the refractory and the metal at all firing rates; and the ability to use the burners in the air-fuel mode for holding, casting, alloying, and initial furnace heat up. Customer data supports the conclusion that air-oxy-fuel is often the best fit for side-well reverb furnaces.

Side-well Reverb Furnace Performance

Air Products' air-oxy-fuel technology has been used in reverb furnaces since 1993 where it has been shown to improve production and fuel economy, lowering operating costs. Our patented burner design delivers high efficiencies and melts rates, while limiting NO_x emissions. Oxygen is only used during the melt cycle when the burner is on high fire, while an air-fuel flame is used for holding, alloying, and tapping.

The major cost benefit of our air-oxy-fuel technology comes from the increased production, which lowers the fixed cost per pound. Results from a side-well furnace are shown in Figure 4.

[1] C.E. Baukal, Ed., *Oxygen-Enhanced Combustion*. New York: CRC Press, 1998.

	Air-fuel	Air-oxy-fuel
Daily Production	156,000 lb.	210,000
Daily Gas Bill	$1,560	$1,050
Daily Oxygen Bill	0	$790
Daily Fixed Cost	$6,000	$6,000
Daily Variable Cost (electric, disposal, salt, etc.)	$1,950	$2,620
Total Daily Cost	$9,510	$10,460
Total Cost per Pound	6.10 cents	4.98 cents

Figure 4: Air-fuel vs. Air-oxy-fuel in a Side-well Reverb Furnace

If we assume the air-fuel operation makes a profit of 1.5 cents per pound processed, then the monthly profit for air-fuel comes to $70,200. Air-oxy-fuel technology reduces the cost by 1.12 cents per pound, so the new profit per pound would be 2.62 cents, or a monthly profit of more than $165,000. This calculation assumes extra production can be sold for the same price as the base business. The net reduction in processing costs, which is greater than 18%, also gives the operation the ability to expand their current market or reduce pricing. Payback for this technology can often be measured in months.

Note that the cost per pound for both natural gas and oxygen is currently lower than the cost of natural gas alone for the air-fuel case (approximately 1 cent per pound for air-fuel vs. 0.88 cents for air-oxy-fuel).

Direct Charge Furnaces and State-of-the-art Burner Design

Full oxy-fuel has been successfully applied to direct charge furnaces where the scrap is placed into the melting chamber without the use of a side-well. There are several burner technologies which can be used in these furnaces and the right choice depends on the customer's operation.

Using burners designed to limit free oxygen in the furnace atmosphere has achieved 2% improvement in yields. Techniques for moving the flame have also contributed to efficient high-yield melting, while flameless combustion burner designs can provide even heating throughout the furnace chamber with high convection heat transfer.

A major concern for all aluminum producers is metal yield. The loss of metal to oxidation or poor furnace practice is one of the most significant costs for an operation. For example, if a producer is melting 10 million pounds a month and the recovery drops from 90% to 89% on a particular material, that translates to a loss of 100,000 pounds of metal—which at $1.00 a pound is worth $100,000. On an annual basis the loss is more than $1 million. For this reason, Air Products has spent considerable time and effort designing and testing burners which minimize free oxygen in the melt chamber. Some field testing has been undertaken with this technology with very promising early results showing higher yields achieved, while maintaining production rates and fuel efficiencies.

For direct charge furnaces, the concern about metal yield often comes from direct contact between the flame and the scrap pile as it gradually melts into the bath. If the flame hits the scrap, the designed mixing of the gases is interrupted and very hot scrap can be exposed to free oxygen. One technique that has been successfully used to overcome this issue is to have an oxy-fuel flame move back and forth across the scrap pile to avoid overheating any one area. Additionally, the flame length can be controlled to minimize any affect on mixing the gases so there is no overheating and no free oxygen. This technology has reduced dross formation compared to air-fuel by over 20% at several European installations, while at the same time increasing production and reducing fuel usage. Paybacks for this type of performance can often be measured in months.

Another advance in technology that has been applied to aluminum melting for reverb furnaces is flameless combustion, also known as low temperature oxy-fuel. In this process, the burner is designed to mix the furnace gases with the natural gas and oxygen in such a way that it dilutes the heat released in the localized area of the burner, and spreads the heat evenly throughout the furnace. As the name “flameless” suggests, the flame is much less visible than a normal flame because the chemical reaction between natural gas and oxygen (the flame) is spread evenly throughout the furnace rather than being concentrating in one specific area of the furnace. Compared to first generation oxy-fuel burners, flameless combustion has been shown to improve melt rates, yield and fuel usage.

Conclusion

Oxygen technology may provide significant commercial and operational advantages to aluminum processors.
Air-oxy-fuel often provides the optimal solution for side-well reverb furnaces, while newer burner designs using 100% oxy-fuel and flames that move across the scrap have been successfully applied to direct charge furnaces. Operational experience and know-how is important to achieving the full benefit of these technologies and Air Products has significant experience with the use of oxygen in aluminum melting. Processors interested in learning more can contact Air Products—our application engineers can provide more information and put you in touch with long term customers who can share their experience and provide feedback on Air Products’ technologies and customer support.

For more information, please contact us at:

Corporate Headquarters
Air Products and Chemicals, Inc.
7201 Hamilton Boulevard
Allentown, PA 18195
Tel 800-654-4567
Fax 800-272-4449
Email gigmrktg@airproducts.com

tell me more
www.airproducts.com

 334-10-002-US