Oxygen-Enhanced Combustion Provides Advantages in Al-Melting Furnaces

Stewart Jepson, Air Liquide Industrial U.S. LP, Countryside, Ill. and
Peter Van Kampen, Air Liquide ACI LLC, Kennesaw, Ga.

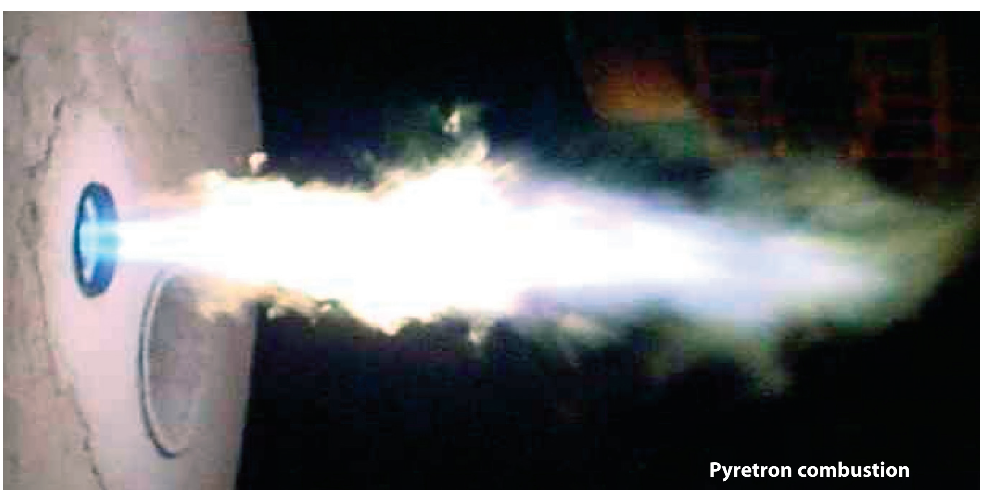
Use of Air Liquide O_2-enhanced combustion technology in several aluminum melt furnaces has demonstrated increased productivity, reduced melt energy cost and reduced emissions, while melt loss remained unchanged or was slightly lower.

In fuel-fired aluminum melting furnaces, O_2-enhanced combustion can provide increased productivity via increased melt rate, melt energy cost savings, reduced emissions and reduced melt loss (increased aluminum recovery). In most cases, an O_2 combustion system is selected for retrofit to an existing melt furnace originally utilizing a 100% combustion air system to accomplish at least one of the above objectives. O_2 combustion systems can be either 100% oxy/fuel (no combustion air) or a combination air/oxy/fuel. Factors that influence the optimum type of O_2 combustion system for a particular furnace include type of furnace (well-charged reverb, direct-charged reverb, rotary), type of charge materials (clean vs. oily or coated, thick vs. thin-wall), number and location of burners, level of combustion air preheat (cold air, recuperator or regenerative burners) and relative cost of fuel and O_2.

General principles behind the benefits of O_2 combustion and optimal application of O_2 combustion technology for various types of aluminum melting furnaces are discussed in this article, and are supported with several furnace case studies.

Case studies

Well-charged (flat bath) reverberatory aluminum scrap-melting furnaces–cold air combustion. Typically, preheated air systems (recuperator or regenerative burners) have not been used in these furnaces because salt fluxing and impurities in the scrap mix can cause severe corrosion or fouling in downstream recuperators. Dust and oxide particulate carryover together with salt fumes and scrap-based impurities can prematurely clog the regenerative burner beds, causing excessive maintenance delays. The capital cost, physical size and mechanical installation requirements for either a recuperator or a regenerative burner system can be prohibitive.


Pyretron combustion

Oxygen combustion enhancement can significantly increase productivity and reduce overall melt energy cost in these melters, and the Pyretron variable ratio air/oxy/fuel system has achieved 20-50% melt rate increases in several installations. The use of 100% oxy/fuel burners can provide similar production increases in this type of furnace. However, higher flame temperatures and smaller flame volumes of 100% oxy/fuel (i.e., more localized heat distribution) pose a greater risk of localized overheating, which can lead to refractory damage and/or increased melt losses. It is important with any O_2 combustion technique (especially 100% oxy/fuel) to control burner firing rate based on both melt and furnace roof temperatures to eliminate the risk of overheating.

Air Liquide has never observed an increase in melt loss using O_2 enhanced combustion. Melt loss has remained the same or been reduced in Pyretron and other O_2 combustion installations because faster melting reduces overall exposure to the combustion atmosphere.

In the past when natural gas prices were lower, use of O_2 in aluminum melting was usually justified based on increased furnace productivity alone (when desired). Companies could tolerate the slight increase in net melt energy cost (total fuel + O_2 cost/lb melted), because the cost penalty was greatly exceeded by the value of the incremental production. By comparison, with today's higher natural gas prices, use of O_2 in aluminum melting usually provides an overall decrease in net melt energy cost with or without an accompanying productivity increase.

Table 1 compares calculated net melt energy cost (fuel + O_2) and profitability for varying levels of O_2 participation used to achieve a desired 33% production increase in an a 60 ton, 60 MMlb/yr, air/fuel, cold air, well-charged reverb melter equipped with O_2 enhanced combustion. The typical Btu/lb and O_2 scf/lb consumption values are based on Air Liquide's U.S. installation experience (actual values for individual furnaces may vary).

There are diminishing returns as O_2 use is increased toward 100%. For example, increasing O_2 participation from 25 to 75% doubles O_2 consumption, but only reduces fuel consumption by 27%. Therefore, using as little O_2 as possible to achieve the desired productivity increase minimizes melt energy cost (maximizes profitability). In other words, melt energy cost is lower with air/oxy/fuel than with 100% oxy/fuel at this particular fuel/ O_2 cost ratio. Overall profitability improvement would typically provide a payback time of less than 1 year on the cost of implementing the Pyretron system in this example.

These results are shown graphically in Fig. 1 using 60°F (15°C) combustion air with production held constant at 60 MMlb/yr. Figure 5 shows as fuel cost increases, O_2 use can be justified on melt energy cost savings alone (with or without a production increase; a productivity increase would only make O_2 look more attractive). At fuel/O_2 cost ratios below about 1.3, air/fuel typically provides the lowest melt energy cost (at lower natural gas prices of the past). Air/oxy/fuel provides the lowest melt energy cost for fuel/ O_2 cost ratios between about 1.3 and 3.0 (today's higher natural gas prices). This is where the flexibility of the variable ratio Pyretron air/oxy/fuel system can really pay off; it can operate in a 25 to 75% O_2 participation range (or higher and lower levels as necessary) to minimize overall melt energy cost (fuel + O_2) for any fuel/ O_2 cost ratio.

Use of 100% oxy/fuel theoretically provides the lowest melt energy cost at a fuel/ O_2 cost ratio higher than about 3.0. However, potential savings are small and must be weighed against possible detrimental effects, such as higher flame temperature and smaller flame volume, which can lead to localized overheating with possible refractory damage and/or increased melt losses. Lower furnace pressure can increase air infiltration to negate any theoretical combustion efficiency gains.

Today's aluminum reverb melting energy costs usually exceed $0.01/lb, and can approach $0.02/lb. Melt energy cost usual-

Principles of O_2 combustion technology:

Air contains 21% O_2 (oxygen) and 79% inert N_2 (nitrogen). In a conventional air/fuel combustion system, the O_2 in air reacts (combusts) with fuel (hydrocarbon), such as natural gas (mainly CH_4) to liberate heat energy, creating CO_2 and H_2O (water vapor):

$$1CH_4 + 9.524air\ (0.21\ O_2 + 0.79N_2) \rightarrow 1CO_2 + 2H_2O + 7.524N_2 + heat \quad \text{[Eq. 1]}$$

Equation [1] illustrates the 10:1 rule of thumb for air-natural gas combustion. 10 volumes (scf) of combustion air per 1 volume (scf) of natural gas provide slightly more (5% excess) than the theoretical amount of O_2 required for complete combustion of CH_4 (9.524 scf air per scf CH_4, as shown). Excess air is normally required to ensure complete combustion. Excess combustion air provides excess unreacted O_2 (and N_2) to the furnace atmosphere, and reduces fuel efficiency. Higher excess air levels are typically required with preheated combustion air or when burning oil, because fuel/air mixing is more difficult. At the nominal 10:1 air/gas ratio, 11 volumes of flue gas products are created per 1 volume of natural gas fuel input. Natural gas gross heating value is typically about 1,000 Btu/scf, whereas fuel oils typically contain about 142,000 Btu/gallon.

In Eq. 1, the inert N_2 has a volume at least 7.5 times that of fuel (CH_4) and almost 4 times that of O_2 required, but contributes nothing to the combustion reaction. It simply "goes along for the ride," diluting the combustion reaction, cooling the flame temperature, and carrying heat energy out of the furnace via stack gas exhaust (sensible heat loss, or flue loss).

By comparison, in oxy/fuel combustion, air is replaced by pure O_2, and the N_2 diluent is eliminated, resulting in the combustion reaction:

$$1CH_4 + 2\ O_2 \ \text{---}{>}\ 1CO_2 + 2H_2O + heat \quad \text{[Eq.2]}$$

Equation 2 illustrates the 2:1 rule of thumb for oxy-natural gas combustion; i.e., 2 volumes (scf) of O_2 are required per 1 volume (scf) natural gas, and 3 volumes of flue gas products are created per 1 volume of natural gas fuel input. Excess oxidizer (O_2) requirements are lower than with air/fuel systems since fuel/ O_2 mixing is improved (no N_2 dilution).

Equations 1 and 2 represent two extremes: 100% air/fuel combustion and 100% oxy/fuel combustion. However, a combination of air and O_2 can be used. The term "oxygen participation" refers to the % of total combustion O_2 requirements supplied by pure (purchased) O_2. For example, 25% O_2 participation means that 25% of combustion O_2 requirements are supplied via purchased O_2, and 75% is supplied by air. The relationship of oxygen participation to oxygen enrichment is given by:

$$c = 0.21/\ (1 - 0.79p) \quad \text{[Eq.3]}$$

where c is oxygen concentration in the mixed oxidizer stream (hypothetical mix of O_2 and air together). Enrichment level (e) is c minus 0.21 (additional O_2 concentration above the level in air; i.e., 0.21). For example, if $p = 0.25$, then $c = 0.26$ and $e = 0.05$ (i.e., 25% O_2 participation is equivalent to 5% O_2 enrichment).

As % O_2 participation is increased, the amount of dilution N_2 pushed through the burner into the furnace and out the exhaust stack is decreased. This reduces the amount of heat energy lost through the flue gas exhaust (flue loss or sensible heat loss), which increases the % available heat (% of input heat made available to the furnace process). Percent available heat (or combustion efficiency) is equivalent to 100% minus flue gas sensible heat losses, where 100% normally refers to the gross heating value of the fuel.

Figure A illustrates the increase in furnace % available heat with increasing O_2 participation, for 60°F (~16°C) combustion air. For example, at a 2100°F (1150°C) furnace temperature, 100% oxy/fuel provides more than double the % available heat (combustion efficiency) of air/fuel combustion, meaning that less than one-half the fuel Btu input is required.

In some instances, preheating combustion air via recuperator or regenerative burners can be used as an alternative to O_2 to improve combustion ly represents the single highest conversion cost item for an aluminum melt/cast facility (not including raw materials). As such, it can represent a significant opportunity for savings. Use of O_2 may be worth reconsidering with today's higher fuel (natural gas) costs of $6-10 versus $3-5. Pyretron systems have also been successful in furnaces using recycled oil (a lower cost alternative to natural gas).

Direct-charged reverberatory aluminum melting furnaces and rotary furnaces–cold air combustion. Average Btu and O_2 consumption are lower for cold-air, direct-charged reverb melters than for well-charged furnaces. Direct flame/flue gas exposure to cold, high-surface area charge materials (scrap pile) provides both higher heat transfer rates and fuel efficiency, especially early in the batch heating cycle. Once the bath has become flat and heated up to pouring temperature, the furnace is poured (after required alloying and stirring) and recharged for the next melt cycle. Overall average fuel consumption for cold air/fuel burners is about 1,800 Btu/lb versus about 2,200 Btu/lb for well-charged (flat bath) melters. Rotary furnaces can have even higher fuel efficiency, because the hot refractory rotates to transfer more heat to the charge/bath via direct contact. (Direct charging oily scrap can further reduce effective Btu/lb requirements in rotary furnaces due to combustion of the evolved hydrocarbons.)

Similar to well-charged furnaces, air/oxy/fuel usually provides the lowest overall melt energy cost together with optimum overall heat transfer (highest productivity increase) for cold-air direct-charged reverbs and rotary furnaces. The only difference is slightly lower overall Btu and O_2 consumption. An additional benefit of Pyretron air/oxy/fuel for these furnaces is its flexibility to adapt to different stages of the batch melting cycle. For example, O_2 consumption can be further reduced during holding time periods (pouring, stirring and alloying) that have low firing rates, further reducing overall melt energy cost.

The melt rates in several rotary furnace installations processing both dross and scrap were increased by 50% or more using Air Liquide oxy/fuel and air/oxy/fuel burner systems, while melt losses remained the same or decreased. Table 2 summarizes experience with rotary-furnace installations in the U.S., showing calculated performance for a 10-ton rotary melting furnace (charging dry scrap) using O_2 participation levels of 25 to 100% to accomplish a 50% melt rate increase. Similar to the well-charged reverb example in Table 1, air/oxy/fuel offers the lowest overall melt energy cost, and, therefore, the highest profitability. Similar results would be

efficiency. Rather than eliminating N_2, the incoming air (N_2 and O_2) is preheated using waste energy from the outgoing furnace exhaust gases. In practical terms, combustion air preheat systems (recuperative or regenerative) have higher equipment cost, with some ongoing maintenance-related costs, whereas initial equipment cost of O_2 combustion systems is lower, but an ongoing consumable cost (O_2) is introduced.

Figure B compares % available heat for cold air, preheated air at various temperatures and 100% oxy/fuel. For aluminum melt furnaces (2000°F, or 1095°C, exhaust), oxy/fuel provides higher fuel efficiency than recuperative systems (~400-800°F, or 200-430°C, air), or regenerative systems (~800-1500°F, or 430-815°C air). The similarity between Figs. 1 and 2 indicates that to increase fuel efficiency in a combustion process, you need to "manage nitrogen" in the incoming combustion air either by preheating it or getting rid of it.

Figure C illustrates the reduction in flue gas volume with increasing O_2 participation. On an equivalent available heat-delivered basis, flue gas volume reduction is greater due to the reduced fuel input requirement. Normally, particulate emissions are proportional to flue gas volume, so emissions levels (baghouse loading) are typically reduced in proportion to the flue gas volume reduction using O_2 enhanced combustion.

Flame temperature also increases as % O_2 participation increases due to the reduced level of N_2 dilution. This increases the flame's ability to transfer heat, especially by radiation. Reduced N_2 levels also increase the concentration of diatomic molecules (CO_2 and H_2O) in the furnace atmosphere, which further enhance the radiative heat transfer performance of the flame. Radiative heat transfer is proportional to the flame temperature to the 4th power minus the load temperature to the 4th power, so the flame radiates heat preferentially to the cooler furnace load rather than to the refractory.

The general benefits of O_2 combustion are to improve fuel efficiency (% available heat), reduce flue gas volume (which reduces emissions) and increase heat transfer from the flame to the load (increase productivity).

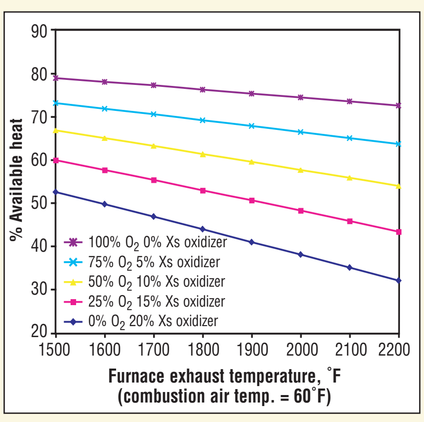


Fig. A Combustion efficiency for varying percent oxygen participation

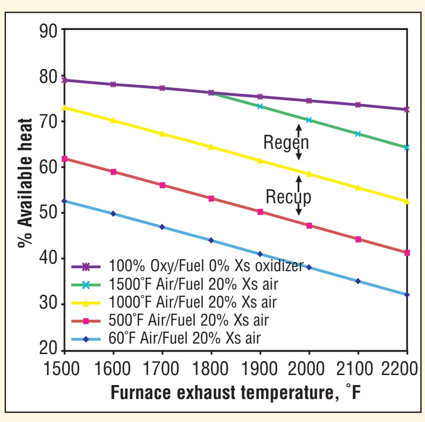


Fig. B Combustion efficiency for preheated air versus oxy/fuel

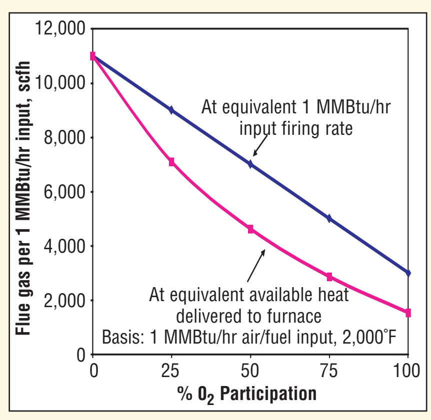


Fig. C Flue gas volume versus percent oxygen participation

expected for processing dross.

The slightly lower flame temperature, higher flame volume and overall improved convective heat transfer characteristics of Pyretron air/oxy/fuel are more suitable than the smaller, hotter 100% oxy/fuel flame for direct-charged reverb melters and rotary furnaces. Pyretron air/oxy/fuel provides broader, more uniform heat distribution in rotary furnaces; the increased flame volume provides higher furnace pressure to minimize air infiltration. Oxy/fuel flames can tend to "tunnel" a hole through the scrap pile (especially light-gage scrap) in a direct-charged melter. Therefore, it is necessary to orient and control oxy/fuel burners carefully to avoid direct flame impingement and subsequent overheating and increased melt loss. The Pyretron air/oxy/fuel flame is better suited for direct flame impingement or direct over-firing of the scrap pile. Use of O_2 also reduces flue gas volume (see Fig. 3), which is especially important in rotary furnaces, because dust loading and effective baghouse capacity is proportional to total burner flue gas volume.

Direct charging of oily (hydrocarbon-containing) scrap. In well-charged reverbs, scrap typically is dried (or delac-

Table 1. **Production increase and melt energy cost savings with O_2 (60˚F combustion air) for a 60 ton well-charged aluminum reverb melt furnace**

	0% O_2 air/fuel	25% O_2 air/oxy/fuel	50% O_2 air/oxy/fuel	75% O_2 air/oxy/fuel	100% O_2 oxy/fuel
MM lb/yr	60	80	80	80	80
Production increase	–	33%	33%	33%	33%
Btu/lb	2,200	1,500	1,250	1,100	1,000
O_2 scf/lb	0	0.9	1.4	1.8	2.1
$/year fuel	$858,000	$780,000	$650,000	$572,000	$520,000
$/yr O_2	$0	$252,000	$392,000	$504,000	$588,000
Total fuel + O_2 ($/yr)	$858,000	$1,032,000	$1,042,000	$1,076,000	$1,108,000
Total fuel + O_2 ($/lb)	$0.0143	$0.0129	$0.0130	$0.0135	$0.0139
Margin ($/lb)	$0.0200 assumed	$0.0214 improved	$0.0213 improved	$0.0209 improved	$0.0205 improved
Profit ($/yr)	$1,200,000	$1,712,000	$1,702,000	$1,668,000	$1,636,000
Improved profitability ($/yr):		**$512,000**	**$502,000**	**$468,000**	**$436,000**

Assumed fuel price = $6.50/MMBtu, with $3.50/1,000 Scf O_2
Fuel/O_2 cost ratio = 1.86

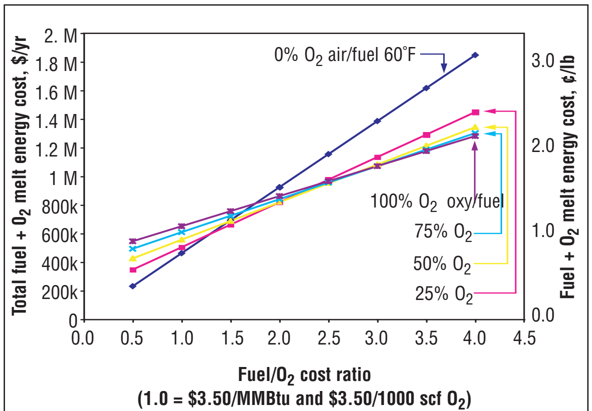


Fig. 1 Energy cost for a 60 MMlb/yr aluminum reverb melt furnace

Pyretron variable ratio air/oxy/fuel combustion technology

Figure D shows Air Liquide ACI's patented Pyretron variable ratio air/oxy/fuel combustion method. Pyretron uses separately controlled combustion air and O_2 feeds, which allows one to vary % O_2 participation to control flame temperature and maximize heat transfer to the metal while limiting the risk of overheating refractory. The two-stage combustion approach enhances radiative heat transfer by pyrolyzing a portion of the fuel in the first fuel-rich O_2-combustion zone. This higher temperature inner flame core is surrounded by the cooler air-based combustion zone, where combustion is completed. Refractory and load exposure to the inner high temperature O_2 flame core is minimized.

Pyretron uses a combination of air and O_2 to produce a bushy, luminous flame having an optimum combination of flame temperature and flame volume to maximize heat transfer via both radiation and convection. Pyretron flame temperature can be increased to nearly that of 100% oxy/fuel, but with greater flame volume. While 100% oxy/fuel burners simply maximize flame temperature, Pyretron air/oxy/fuel maximizes overall heat transfer characteristics to provide maximum furnace production capacity. Also, since most furnaces have not been specifically designed for 100% oxy/fuel, the small 100% oxy/fuel flame volumes can create additional air infiltration, negating any theoretical thermal efficiency improvements.

Pyretron also usually provides the lowest overall melt energy cost by optimizing the use of purchased O_2 and combustion air. In terms of fuel efficiency improvement (and heat transfer improvement) per incremental quantity of O_2 used, there are diminishing returns as O_2 use increases towards 100%. With Pyretron, O_2 participation can be increased during melting and reduced during furnace holding time or delays. This flexibility allows further optimization of melt energy costs and minimizes risk of overheating.

The Pyretron method provides more controllable flame characteristics than O_2 enrichment, O_2 lancing and other modifications to air/gas burners. State-of-the-art controls provide a wide turndown range and accurate ratio control over a wide range of firing rates. Accurate turndown control improves furnace temperature control, which can contribute to further energy savings.

In situations where NOx is a serious limitation, 100% oxy/fuel can provide lower NOx emissions than air/oxy/fuel or air/fuel, and 100% oxy/fuel could be the best (only) choice in these cases. However, most U.S. aluminum melting facilities are classified as minor sources of NOx emissions, and, therefore, NOx emissions from melt furnaces are usually not a serious limitation. Typically, Pyretron air/oxy/fuel will provide about the same overall NOx emissions (lb NOx/lb Al) as air/fuel due to the improved fuel efficiency.

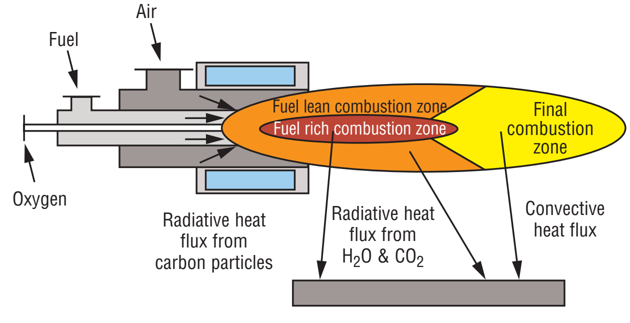


Fig. D Pyretron air/oxy/fuel combustion method

quered) usually in a rotary kiln scrap dryer, to remove moisture including hydrocarbons (coatings, oils, etc.) before charging. Yield is improved by submerging into the well (especially light gage scrap) as opposed to exposing it to direct flame impingement. If scrap is not dried/delacquered before submerging in the well, the volatilized hydrocarbon bubbles can burst at the well surface, increasing molten metal surface area exposure to air, leading to increased melt loss.

Charging oily (e.g., oily turnings), coated and painted scrap directly into direct-charged aluminum reverbs and rotary furnaces provides additional hydrocarbon fuel value. In some rotary furnaces, taking advantage of this "free" energy source (burning evolved hydrocarbons) reduces purchased fuel requirement to as low as 1,000 Btu/lb, even with cold air combustion. However, careful control is required using this practice because overheating the overhead exhaust canopy and exhaust ductwork is possible if too much energy is released too quickly and/or if insufficient air is provided to combust rapidly evolving hydrocarbons. Using a combination of O_2 and combustion air can help to more rapidly and effectively combust hydrocarbons in the furnace, and transfer the heat to the scrap charge. The author believes that injecting 100% O_2 is too aggressive and could lead to localized overheating with excessive melt loss and/or refractory damage. An O_2/combustion air mix can provide the right combination of burning speed and flame volume for broader heat distribution within the furnace.

Excessive O_2 injection can lead to excessive melt loss. Therefore, Air Liquide developed feedback-based control technology (based on either temperature or exhaust-gas concentration, or both) to automatically inject the optimum amount of O_2 (or air/ O_2) to burn hydrocarbons in rotary and direct-charged reverbs (especially when charging oily scrap).

The company's most advanced feedback-control incorporates a diode laser-based exhaust gas concentration measurement technology (tunable diode laser, or TDL), which provides essentially instantaneous information on species concentration (CO, CO_2, O_2) as they evolve. This eliminates the extractive-sampling delay

Table 2. Production increase and melt energy cost savings with O_2 (60°F combustion air) for a 10 ton rotary aluminum scrap melting furnace

	0% O_2 air/fuel	25% O_2 air/oxy/fuel	50% O_2 air/oxy/fuel	75% O_2 air/oxy/fuel	100% O_2 oxy/fuel
MM lb/yr	55	70	70	70	70
Production increase	–	27%	27%	27%	27%
Melt rate increase	–	50%	50%	50%	50%
Btu/lb	1,800	1,310	1,130	1,000	900
O_2 scf/lb	0.00	0.75	1.25	1.60	1.85
$/year fuel	$643,500	$596,050	$514,150	$455,000	$409,500
$/yr O_2	$0	$183,750	$306,250	$392,000	$453,250
Total fuel + O_2 ($/yr)	$643,500	$779,800	$820,400	$847,000	$862,750
Total fuel + O_2 ($/lb)	$0.0117	$0.0111	$0.0117	$0.0121	$0.0123
Margin ($/lb)	$0.0200 assumed	$0.0206 improved	$0.0200 same	$0.0196 reduced	$0.0194 reduced
Profit ($/yr)	$1,100,000	$1,439,200	$1,398,600	$1,372,000	$1,356,250
Profitability improvement ($/yr):		**$339,200**	**$298,600**	**$272,000**	**$256,250**

Assumed fuel price = $6.50/MMBtu, with $3.50/1000 scf O_2
Fuel/O_2 cost ratio = 1.86

Table 3. Pyretron air/oxy/gas results in a 185,000 lb direct-fired aluminum melter

	Original	With Pyretron
Combustion system	4 Air/gas burners	4 Pyretron air/oxy/gas burners
Max. total firing rate, MMBtu/hr	50	60
Air preheat temperature, °F	750	750
Avg. melt rate, lb/hr	40,000	48,000 (20% increase)
Natural gas consumption, Btu/lb	1,240	1,130
Oxygen consumption, scf/lb	–	0.18
Gas + O_2 cost per lb	–	unchanged
Metallic yield	–	unchanged

Table 4. Hypothetical supplementary oxy/fuel firing in a 60,000 lb direct-charged aluminum extrusion scrap melter with regenerative burner pair

	Original air/gas regen burner pair @ 24 MMBtu/hr capacity	Regen pair at 20 MMBtu/hr plus supplementary 8 MMBtu/hr oxy/fuel firing
Melt time, hr	3.00	2.30
Hold/cast time, hr	2.50	2.50
Total cycle time, hr	5.50	4.80
lb/yr	94,254,545	108,000,000
Overall production increase	–	15%
Melt rate increase	–	30%
Melting firing rate, MMBtu/hr	24.0	28.0
Melting O_2, scfh	0	16,000
Melting air, scfh	274,286	228,571
Melting total flue gas, scfh	298,286	272,571
Melting, Btu/lb	1200	1073
Melting O_2, scf/lb	0	0.613
Holding firing rate, MMBtu/hr	6.0	6.0
Holding O_2, scfh	0	0
Holding, Btu/lb	250	250
Holding, O_2 scf/lb	0	0
Total Btu/lb	**1,450**	**1,323**
Total O_2, scf/lb	**0**	**0.613**
$/yr fuel	$888,349	$928,980
$/yr O_2	$0	$231,840
Total fuel + O_2 ($/yr)	$888,349	$1,160,820
Total fuel + O_2 ($/lb)	$0.00943	$0.01075
Margin ($/lb)	$0.02000 (assumed)	$0.01868 (slightly reduced)
Profit ($/yr)	$1,885,091	$2,017,080
Profitability improvement ($/yr)	**–**	**$131,989**

Assumed average air preheat temperature = 1300°F.
Assumed fuel price = $6.50/MMBtu, with $3.50/1000 scf O_2
Fuel/O_2 cost ratio = 1.86

associated with conventional "probe with sample pump" analyzers (and eliminates sample probe, pump and filter-related maintenance concerns). Field demonstrations on full-scale melt furnaces show that this technology provides reduced fuel and O_2 consumption, increased melt rate and reduced melt loss (1+% increase in aluminum recovery). Increased aluminum recovery is especially valuable because a 1% reduction in melt loss is equivalent to a 1% reduction in raw material (scrap) costs, or a 1% increase in product sales.

Direct-charged aluminum reverb melting furnaces–preheated combustion air. Some direct-charged furnaces melting relatively clean scrap and prime incorporate regenerative burners or a recuperator to preheat combustion air using energy from the furnace exhaust gases. Fuel efficiency can be increased in these furnaces to near the level attainable with O_2 by preheating combustion air (see Fig. 2). Replacing an existing regenerative burner system or recuperator with air/oxy/fuel or oxy/fuel combustion is usually not economical. Use of O_2 to supplement the existing preheated air combustion system rather than replace it can boost production or provide energy cost savings, or both.

For example, Pyretron systems were installed in two 185,000-lb direct-charged, round-top melters in a large U.S. aluminum rolling mill producing canstock. Each furnace employed a recuperator to preheat combustion air up to 750°F (400°C) to four air/gas burners firing directly on the prime/scrap charge mix (including coils). Table 3 shows that melt rate was increased by 20% using supplementary fuel and O_2 (with preheated combustion air) through specially designed retrofit Pyretron air/oxy/gas burners. Net melt energy cost (natural gas + O_2) was unchanged. (A net melt energy cost reduction would have resulted at today's natural-gas prices.) Supplementary O_2 was turned off when the furnace reached flat-bath conditions, as burner firing rate automatically turned down to maintain temperature.

With this furnace, the main advantage of using O_2 was the ability to input more Btus with both minimal additional flue gas volume and enhanced flame heat transfer characteristics (higher energy transfer/available load surface area). This was especially important in this example due to fixed recuperator volume capacity.

The same concept could be applied to furnaces using regenerative burners. For example, some direct-charged scrap melting furnaces use regenerative burners operating in pairs. A regen burner pair, while providing high fuel efficiency (low Btu/lb) via high air preheat, can compromise the heat distribution pattern. Alternate firing between burners effectively has the pair operating as one large burner. Heat distribution is not optimum, especially in furnaces with only one regen burner pair, because the scrap pile is heated by only one (large) burner at a time. It could be cost- and/or space-prohibitive to use more than one pair of regen burners (which are quite large in size) in some furnaces. Use of relatively small, compact supplementary oxy/fuel burners to input heat at additional furnace locations can provide more uniform heat distribution, resulting in faster meltdown. Oxy/fuel burners introduce supplementary energy input at high thermal efficiency with minimum additional flue gas volume. The burners can be turned off after meltdown, during holding time periods (alloy, stir, cast).

Table 4 shows the calculated performance with supplementary 8 MMBtu/hr oxy/fuel firing to a 24-MMBtu/hr capacity regen burner pair in a hypothetical 60,000 lb direct-charged extrusion scrap melter. In this example, the regen burners are de-rated slightly to 20 MMBtu/hr with the supplemental oxy/fuel firing to provide more balanced heat distribution. The small additional firing capacity potentially allows acheiving a substantial melt rate increase with reduced flue gas volume and combustion air requirement. In practice, the firing rates of both the regen burners and supplemental oxy/fuel burners can be adjusted to obtain optimal heat distribution balance for the best combination of productivity and melt energy cost. There can be a slight increase in net melt energy cost (fuel + O_2) due to the very high efficiency of the regen burners. But, the value of increased productivity far outweighs the slight energy cost penalty in situations where increased productivity is desired (payback time should be about 1 year or less). Careful positioning and control of supplementary oxy/fuel burners based on roof or flue gas temperature is required to avoid refractory damage or melt loss. **IH**

For more information: Stewart Jepson, Technology Development Mgr., Air Liquide Industrial U.S. LP, 5230 South East Ave., Countryside, IL 60525; tel: 708-579-7847, e-mail: stewart.jepson @airliquide.com; www.airliquide.com. Peter Van Kampen, Mgr., Non-Ferrous Business Development, Air Liquide ACI LLC, 200 Chastain Center Blvd. #295, Kennesaw, GA 30144; tel: 678-354-8233; e-mail: peter.vankampen@airliquide.com.

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