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Enhanced Energy Efficiency and Emission Reduction in the Aluminum Remelting Industry

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ABSTRACT

This paper describes a high flame temperature oxy-fuel combustion technology for re-melting aluminum that significantly reduces energy consumption and emissions. This oxy-fuel combustion technology developed by Jupiter Oxygen is a patented process for combustion of fossil fuels with pure oxygen while excluding air, thereby creating a high flame temperature and increased efficiency for process heating in industrial furnaces. This unique process has led to improved heat transfer while maintaining the same wall, roof and melting process temperatures as with air combustion. The energy efficient combustion process allows aluminum companies to operate at a substantially lower cost due to a dramatic fuel savings of up to 70% for natural gas and waste oil. The results of more than 12 years of day-to-day experience utilizing the Jupiter Oxygen Corporation oxy-fuel combustion technology licensed to Jupiter Aluminum Corporation in the aluminum re-melting business are discussed as well as the potential for applications in the Indian aluminum industry.

1. INTRODUCTION

Aluminum industry average aluminum re-melting heat requirements are approximately 2200 BTU per pound (5,166.843 KJ/KG) of scrap (2). The heat requirements of melting aluminum scrap is a major contributor to the variable cost. In the Mid-1990s, Jupiter Aluminum Corporation (JAC) was faced with escalating fuel prices and undertook a dedicated private research and development program designed to reduce fuel consumption. In order to make combustion a more efficient process, Dietrich Gross, envisioned the use of oxygen instead of air. This vision, combined with a rigorous research and development program, produced a viable business solution. The use of oxygen in moderate temperature processes, such as aluminum recycling, had previously not been successful.

The results obtained through the use of the patented Jupiter Oxygen Corporation (JOC) process have been significant. Fuel consumption has been recorded at 750 BTU per pound (1,744.378 KJ/KG) of aluminum melted in a continuous operation, and NOx generation is virtually zero from the combustion of natural gas. Retrofitting is accomplished with minimal downtime, utilizing equipment in accordance with JOC specification and process. Most of the JOC oxy-fuel combustion system can be installed while the furnace continues to operate on air. The only downtime required for installation is final piping, and installation of oxy-fuel burners and ram refractory around the burner block. No refractory degradation has been experienced due to the high temperature of the flame (4500–5300 degrees Fahrenheit/2482–2927 degrees Celsius).

1.1 Jupiter Oxygen Corporation Patented Process and Experience

JOC oxy-fuel combustion technology is a patented process for the combustion of fossil fuels with pure oxygen while excluding air, using a high flame temperature. High flame temperature means that the flame is not cooled by air or recirculated gases. For aluminum recycling furnaces including rotary furnaces, existing furnace materials can be used and the same melting temperatures are maintained. JOC recognized early that the key to success was controlling the heat transfer, not the flame temperature. Flame temperature is a result of mixing fuel and an oxidizer source, while heat transfer is a desired engineering result. The area of heat transfer is how JOC realizes fuel savings. In addition, the proper process control allows the system to operate favorably for aluminum production. To develop, establish and promote the Jupiter Oxygen process, Mr. Gross founded Jupiter Oxygen Corporation in 2001, and patented the technology in the U.S. and worldwide.

1.2 Main Concerns Using Oxy-Fuel Combustion

Aluminum industry concerns center around the following three areas:

- Costs
- Oxidation of metal
- Destruction of refractory material from high flame temperature.

JOC uses a near stoichiometric combustion approach, carefully controlling the levels of excess oxygen in the furnace to limit the formation of oxides in the metal. In addition, the approach or “flame shaping” and radiant heat transfer avoids the turbulent mixing of the hot gases and metal surfaces. JAC has not seen any increase in oxidation of the metal within the furnaces using the techniques developed. Meeting the specific criteria of no increase in metal loss was a key task during the developmental stage. Experiments were designed to quantify the loss of metal and were completed in a small test furnace, while plant wide data was used to confirm the test results after scale up to the larger melting furnaces.

Refractory materials in aluminum furnaces commonly degrade around 3000˚F (1649°C) at the high end, with other refractory degrading at lower temperatures. It was undesirable to upgrade or replace the common refractory material used in JAC furnaces. So, through observation of refractory life and temperature measurement, it has been determined that no refractory life issues have arisen. In fact, refractory life has generally been longer with less frequent hot spotting failures or mechanical failure associated with scale build up.

There are several factors which contribute to this. First is the dependence on radiant heat transfer rather then convection to the metal bath. By evenly distributing the heat according to surface area line of sight, both the bath and refractory walls are more evenly heated with no flame impingement on the metal or walls. In addition, the "reverb" affect of deflecting hot gasses around the furnace is unnecessary due to the low gas volumes (no air means no volumes of nitrogen) and dependence on radiant heat instead of convective. The observed effect was better temperature profiles, meaning less temperature differential in the corners, roof and walls of the furnaces. This also had the effect of preventing scale buildup in the furnaces.

Most importantly are the cost factors for the technology, which by default includes melt loss and additional maintenance. Given that melt loss does not increase and refractory life is not decreased, the pure economics require consideration. While natural gas costs (and other fossil fuels) have generally trended upward since the installation of the JOC oxy-fuel system, the initial payback analysis for the technology was based upon the cost of less then $3.00 per MMBTU. With a fuel consumption rate decreased by up to 70%, significant dollar savings were used to offset the cost to purchase and operate a cryogenic plant.

1.3 Equipment Requirements Utilizing JOC Patented Oxy-Fuel System

The oxy-fuel combustion system designed and operated in accordance with the JOC patented process has been successfully installed in "new build" furnaces and retrofitted to existing furnaces. Existing furnace retrofits have included "box-type" reverb (without side wells), holding and rotary furnaces.

It should be noted that the refractory materials in the furnaces were not changed or altered for the retrofit applications, and the new furnace designs used the same types of refractories, which were of common brands.

The combustion systems include several burners specifically designed for oxy-only firing with certain flame characteristics, including shape and length designed around furnace geometry. The combustion system controls include specific components which have been proven for precision and durability in the environments of re-melting. The operator control stations are tailored to specific plant criteria, including very high level of supervisory control if desired.

The oxygen systems use piping and parts meeting the "clean for oxygen use" specifications for cleanliness, while the oxygen supply can be from liquid (tank), pipeline and on site generation. JAC utilizes two cryogenic plants for its operations, which also co-produce nitrogen for annealing and argon.

2. METHODOLOGY: OXY-FUEL TEST PROGRAM

JAC undertook research into oxy-fuel combustion in its test furnace, aluminum melt furnace No. 7. The test melter holds approximately 15,000 lbs of molten aluminum, while the large production melters hold up to 250,000 lbs. Initial trials with oxy-fuel were designed to determine process parameters and development of components. Foremost was the development of the burner. Oxy-fuel combustion results in high flame temperatures can lead to rapid deterioration and failure of the burner and furnace. Proper burner materials needed to be identified as well as process parameters. Once the burner was refined to the point where it provided consistent combustion and longevity, the trials proceeded.

2.1 Trials and Alternate Fuel Sources

After initial production and installation of oxy-fuel in the larger production melters, both natural gas and alternate fuel sources were tried for a period of time. Alternate fuel sources tried consisted of a variety of used oils. Alternative fuels have been successfully used in production and current fuel selection is dependent on cost.

2.2 Precision Control

During the melt trials, JAC learned the importance of precision control of fuel and oxidant along with flame shaping techniques to control the heat transfer. In the field of aluminum melting, excess oxygen at elevated temperatures will result in aluminum metal oxidation, causing metal loss in the form of additional dross (secondary aluminum melt by-product). One of the most important issues for a melting facility is its metal yield from the melt. It was thought at the time that excess oxygen was required in order to maintain safe operational limits of combustion. Discovery made through testing and trials gave every indication that equipment was available to precisely control the amount of oxidant (oxygen) and fuel (natural gas or other) to the burner. This allowed the use of near-stoichiometric combustion without metal oxidation and eliminating the need for excess oxygen. Early trials with the burners revealed that very low levels of incomplete burned carbon (CO) could be achieved with exceptional flame stability at near stoichiometry. Even below-stoichiometric combustion produced exceptional flame stability, although the CO levels rose as expected.

2.3 Flame Shaping

During the trials, the concept of flame shaping was first investigated. The basic question was: How do we take advantage of the extremely high luminosity resulting from the oxy-fuel flame? Was a short, bushy flame or a long, pencil-like flame the best way to transfer heat into the melt? A restriction on JAC furnaces is that doors are opposite the burner wall which cannot tolerate as high a temperature as other parts of the melting furnace. These doors typically are routinely damaged by the violent impact of the turbulent air-fired burners common to such furnaces. The ultimate design of the burners extended the flames nearly all the way across the furnace with equal spacing throughout. Common practice is to direct the high-temperature gases into the melt to maximize convective heat transfer. This practice was not followed in the development of the JOC process, which relies primarily on radiant heat transfer. Typical temperature ranges within an aluminum melting furnace are as follows: molten aluminum 1350˚F (732˚C), upper wall temperatures between 1800˚F (982˚C) and 2100˚F (1149˚C) and 1600˚F (871˚C) for the stack exhaust. Often aluminum melting furnaces experienced hot and cold spots throughout the furnace area. With JOC oxy-fuel, the process temperatures in the furnace improved, particularly the wall temperatures, which were generally lower and evenly distributed. This even-distribution resulted in longer life of the refractory materials in the furnace and fewer overall furnace failures.

2.4 Furnace and Combustion System Findings

An oxy-fuel furnace, according to the JOC patented process is fed with a carbon based fuel, such as natural gas, in a near stoichiometric proportion with oxygen. The oxygen/natural gas proportions in the present melting and holding furnaces are set at 2.36:1 (1). This proportion of oxygen to fuel provides a number of advantages. First, this stoichiometry provides complete combustion of the fuel, thus resulting in less carbon monoxide, NOx and other noxious off-gas emissions. In addition, the controlled oxygen proportions also reduce the amount of oxides present in the molten aluminum. This, in turn, provides a higher quality final aluminum product, and less processing to remove these undesirable oxide contaminants. It is important to note that accurately controlling the ratio of oxygen to fuel assures complete burn of the fuel.

Oxides in aluminum come from two major sources: (1) the combustion process; (2) oxides that reside in the aluminum. This is particularly so with poor grade scrap or primary metal. The process takes into consideration both of these sources of oxides and reduces or eliminates their impact on the final aluminum product. First, the JOC process reduces oxides that could form as a result of the oxygen fed for the combustion of the fuel. This is achieved by tightly controlling oxygen feed to only that necessary by stoichiometric proportion for complete combustion of the fuel. The present process takes into consideration the second sources of oxides (that residing in the aluminum), and removes these oxides by the degassing and filtering processes.

The benefits are two fold. The first is that less byproduct in the form of dross is formed; second, the quality of the finished product is greatly enhanced. The furnace used to describe the application includes four oxy-fuel burners. Those burners are installed on a side wall of the furnace opposite the doors. Heat is input to the furnace by the burners. Due to the high luminosity the principal mode of heat transfer to the furnace is radiation, with some convective heat transfer. Because of the high flame temperatures, the oxy-fuel combustion system provides efficient radiative heat transfer.

The combustion system provides a number of advantages over known and presently used combustion systems. For example, it has been shown through operation that there is considerable energy savings using the Jupiter Oxygen process. The oxy-fuel burners operate at a much higher temperature than conventional furnaces. Thus, there is an observed increase in the heat available for melt. Fuel savings is attributed to three principal factors. First, the increased heat of the combustion system permits complete burn of all fuel without excess oxygen. Second, the combustion system operates within a radiative (or radiant) heat transfer zone, with some heat transfer by conduction. The system is designed to take advantage of the radiant heat transfer within the furnaces to transfer heat effectively to the metal baths. Third, because there is no nitrogen in the combustion process, the amount of gas flowing through the furnaces is low. Thus, an increased residence time of the hot gases permits the release of a larger proportion of energy (in the form of heat) prior to exhaust from the furnaces.

Typical exhaust gas volume is a fraction of that of conventional furnaces. Since there is about 80 percent less gases (essentially the nitrogen component of air) in an oxy-fueled furnace, combustion efficiency is greatly increased. The present combustion system also provides for increased production. When installed as part of a melting furnace, the melting capacity or throughput of the furnace will be increased. This again is attributed to the rapid and effective heat transfer in the furnace. As new metal is introduced into the furnace, the combustion system responds rapidly to provide heat to melt the feed metal and to maintain the heat (temperature) of the molten metal in the pool at the set point temperature. It has been found that aluminum accepts heat very efficiently from a radiative heat source.

2.5 Oxygen Supply

The choice of a source for oxygen requires knowledge of local conditions. For example is a pipeline or oxygen plant source nearby? For JAC, the purchase of a used oxygen plant was the most economical solution and has proven extremely dependable.

3. RESULTS

JAC monitors its fuel usage on a per day, per pound per furnace basis. JAC melts aluminum during casting operations with a fuel input of 750 to 900 BTU's per pound (1,744.378 to 2,093.254 KJ/KG) melted. The range is due to not utilizing the full melt rates of the individual furnaces at different cast production widths (the Hazelett continuous caster casts at different widths thus the rate at which metal is needed varies). In addition, the technology was retrofitted to the "holding" furnace where no melting takes place. The results showed that the fuel usage for the furnace in a "hold" mode was cut in half. When reviewing yearly data, which includes periods of non-production (no melting or casting), the average usage of fuel based upon high flame temperature oxy-fuel combustion for all melted pounds in 2001 was 1083 BTU's per pound. *Please note that the data provided is actual production and cost data not laboratory data!*

Table 1: Fuel use Reduction Per Pound Aluminum Remelted

	BTU/LB	*FUEL USE*
1997	3,644.94	REDUCTION
2001	1,132.83	68.92%

This oxy-fuel technology has been in every day use at JAC since 1998. The JOC energy efficient combustion process has allowed the aluminum company to operate at a substantially lower cost due to a dramatic fuel decrease, i.e., natural gas fuel reduction up to 74%, oil fuel usage reduction up to 68%, equivalent reduction of CO_2 due to fuel savings and virtually zero NOx.

3.1 Energy Efficiency Gains, Fuel Savings and Greenhouse Gas Emission Reduction Proportional to Oxy-Fuel Technology Implementation

Jupiter Aluminum Corporation started to implement oxy-fuel combustion in 1998 for approximately 27% of its remelting production, followed by 46% in 1999 and 54% in 2000. In 2001, all remelting furnaces were operating 100% on Jupiter oxy-fuel combustion.

Table 2: Oxy-Fuel Technology Implementation at JAC: 1998 to 2001

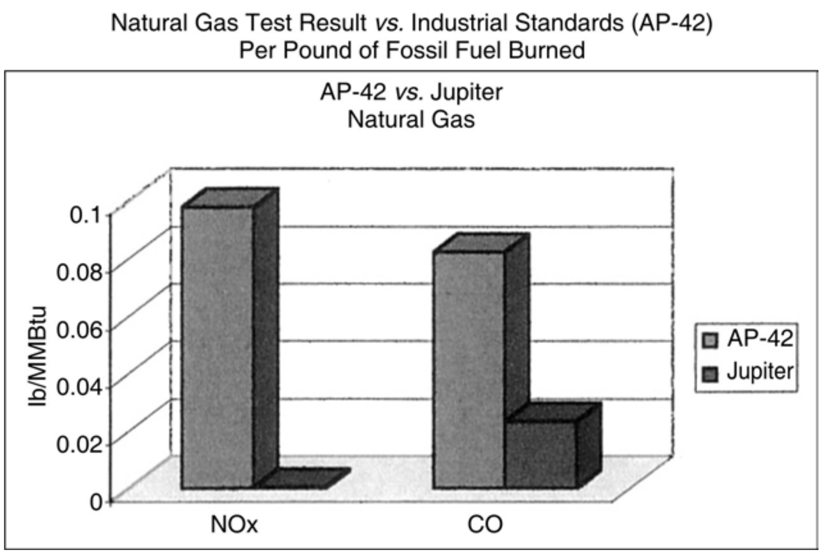
Year	*Estimated*	*Production FCE*						
	Casted Aluminum	*Natural Gas*	*Waste Oil*	*Waste Oil*	*Percent*	*CO_2 - Oil*	*CO_2 - NG*	*CO_2*
	Pounds	*MMBtu*	*MMBtu*	*Gallons*	*Oxy-fired*	*TPY*	*TPY*	*TPY*
1997	134,797,919	605,370.38	**0**	**0**	**0.00%**			
1998	164,041,703	570,063.62	0	0	**26.90%**	0	32,001	32,001
1999	181,984,940	441,750.48	0	0	**46.00%**	0	24,798	24,798
2000	184,773,584	400,809.52	0	0	**53.50%**	0	22,499	22,499
2001	161,286,676	125,018.00	84,516	612,742	**100.00%**	5,930	7,018	12,948

The fuel consumption dropped significantly in proportion to oxy-fuel technology implementation. Table 2 shows a reduction in CO_2 emissions (greenhouse gas) and based on oxy-fuel combustion implementation in spite of increased production.

U.S. data shows a 60% "energy efficiency savings opportunity" per pound aluminum re-melted (2). In fact, JOC oxy-fuel technology has been exceeding this projection since 1998. According to SECAT data and JAC results, an aluminum re-melting facility with today's production of 110,000 metric tons [≈250,000,000 pounds] of aluminum can achieve fuel savings of 318,000 MMBTU annually from JOC oxy-fuel technology implementation. Air-fuel combustion at 2200 BTU per pound requires 538,000 MM BTU/year and an oxy-fuel combustion at 900 BTU per pound requires 220,000 MMBTU/year. Those fuel savings translate into significant cost savings as well as into 15,000 tons of net CO_2 emissions avoided per year. Net CO_2 avoidance takes into account the electricity used for oxygen production and related CO_2 emissions[1].

3.2 Environmental Improvements

In 2001, a series of tests had been conducted at Jupiter Oxygen's test facility, in the premises of the Jupiter Aluminum plant, as part of a Cooperative Research and Development Agreement (CRADA) with the National Energy Technology Laboratory (NETL) of the US Department of Energy (3). The test series documented the achievements in fuel reduction through oxy-fuel technology implementation (see point 4.1) as well as environmental improvements according to the AP-42 standard of the US Environmental Protection Agency (EPA). The EPA AP-42 standard compiles the air pollutant emission factors from various sources of air pollution. In most cases, those factors are simply averages of all available data of acceptable quality, and are generally assumed to be representative of long term averages for all facilities in the source category (4). The following data are test results from the Jupiter oxygen-natural gas firing in a melting furnace. The tests were conducted and recorded by Clean Air Engineering in May 2001. The following test result comparison to the EPA AP-42 standards has been reported to the National Energy Technology Laboratory (US Department of Energy):



Graph 1: NOx and CO Reduction, Firing Oxygen & Natural Gas

[1] The operation of the oxygen plant at JAC requires approximately 11,000 MWh/year.

Table 3: Results from Test Furnace Operating on Natural Gas

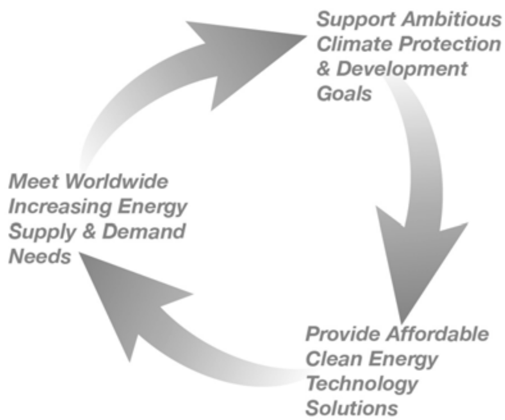
Natural Gas Oxy-Fuel			
	AP-42	*JUPITER*	*% REDUCTION*
NOx	0.098039	0.000494	99.50%
SOx	0.000588	0.000326	44.56%
CO	0.082353	0.023507	71.46%
VOC	0.005392	0.000598	88.91%

4. CAPACITY BUILDING AND FURTHER DEVELOPMENT

In 2008, Jupiter Oxygen signed a strategic alliance agreement with ENCON Thermal Engineers, Faridabad to introduce high flame temperature oxyfuel combustion to the Indian industrial furnace market. ENCON has the exclusive right to use this technology for their customers.

4.1 Cooperative Research and Development with U.S. Department of Energy, National Energy Technology Laboratory [NETL], 15 $MW_{thermal}$ Test Boiler

Encouraged by the favorable results from Jupiter's technology implementation in industrial furnaces, this oxy-fuel technology now is being applied to fossil fuel steam generators and power plants, focusing on energy efficiency and emissions reduction (8). This development also has been done in cooperation with the National Energy Technology Laboratory. In November 2004, Jupiter Oxygen together with the NETL successfully did R&D on a clean coal technology, testing JOC oxy-fuel combustion process and NETL's Integrated Pollutant Removal System. This technology approach is important for a cost effective method to capture carbon and eliminate key pollutants from the existing coal power plant fleet in the U.S. and worldwide (5). JOC operates an oxy-fuel test facility for the development of both aluminum industry and power generation application. Included at the research facility is a 15 $MW_{thermal}$ steam generator for the testing of burners and carbon capture and pollutant control equipment (6).



4.2 Conclusion and Outlook

JOC technology is a cost cutting approach to the increasing costs of fuel in the aluminum re-melting industry. Jupiter's oxy-fuel technology implementation significantly improves fuel efficiency for process heating, increases production rates and has a very favorable environmental record concerning NOx, CO, SOx and VOCs. Significant fuel savings lead to equivalent CO_2 emissions reduction that can be credited to existing or future carbon markets.

Oxy-fuel combustion technology will play an important role for significant fuel savings in industrial furnaces as well as to realize a practical and economic pathway for Carbon Capture and Storage (CCS) strategies. Oxy-fuel technology applications provide the opportunity to increase production while reducing fuel consumption and greenhouse gas emissions and are an important strategy to sustain energy intense industries successfully in a carbon constraint world (7).

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