

Low Ionization Plasma Sources for Enhanced Aluminum Processing for Energy Savings, Environmental Benefit and Increased Productivity

Low ionization plasma melting of aluminum is shown to be effective due to the speed of melting and the highly efficient nature of the process. Additionally, the input power is low as compared to the alternatives, and it produces no noise and no emissions.

Over the years, the aluminum casting industry has been searching for an energy efficient rapid melting device with reduced losses from oxidation and contamination. To accomplish these goals along with energy efficiency, the furnace design must incorporate heating systems that direct highly concentrated heat on the aluminum ingots, sprues or scrap in order to provide rapid and efficient melting. Alternately, a retrofit is required for existing aluminum furnaces that may assist with the rapidity and associated energy saving. Only recently a new mid-temperature range (1200K–1600 K, 1700°F–2420°F) convective-plasma device has been patented and become available. It is commercially known as the PlasmaAirTorch™ [1] shown in Fig. 1.

Thermal Plasma

Non-plasma convective heating is used in the materials processing industry for heat-treatment and melting applications. Plasma enhancement has often been attempted. The research in industrial applications of plasma has largely been concentrated on two types of systems: thermal plasma at atmospheric or near atmospheric pressures and low-pressure plasmas. Thermal plasmas are used extensively in applications such as plasma spray coatings and arc welding. Typical temperature in such applications may be in the range of 5000-15000K and pressure is atmospheric. In the second

case, plasmas at low pressures are used for applications such as chemical vapor deposition and polymer processing. These are generally cold plasmas. Due to low-collision coupling between electrons and heavy particles, the temperature of ions and neutral atoms remains at room temperature.

Thermal plasmas have also received much attention in the literature. However, these two extremes (very hot plasmas at atmospheric pressure or cold plasmas at low pressures) are not best suited for metallurgical work. For example, most of the aluminum melting or steel heat treatment is carried out between 600°C and 1200°C (1110°F–2190°F). The low-pressure plasma possesses very low energy density and cannot be used for aluminum melting. The very high-temperature thermal plasmas result in significant heat losses and may result in poor efficiencies.

Plasma Generator

The 1-atmosphere, patented, plasma generator discussed in this article is able to address both these needs. The device converts air into a low-ionized plasma at 1-atmosphere. The resulting plasma, about 1200°C (2190°F), is able to provide a nitrogen cover to the metal (eliminates cover gas) as well as focused energy and vastly improved heat transfer, both leading to significant energy-efficiency benefits.

A typical device that can easily be attached to any existing furnace is shown in Figs. 1a and 1b. The device shown in Fig.

1c, operates with a fan and produces the required amount of plasma directly from air. Unlike conventional plasma guns, the flow of plasma is gentle and extremely quiet.

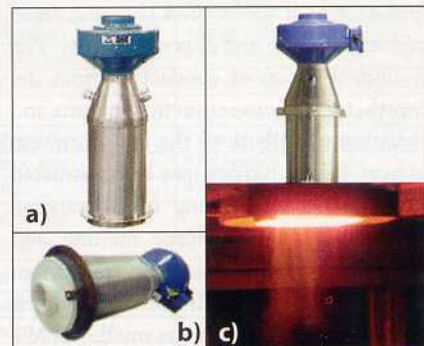


Fig. 1a. A typical 10kW PlasmaAirTorch™ (overall length 25"; diameter 7")

Fig. 1b. A typical nozzle that can be attached (i.e. added-on) to an existing furnace

Fig. 1c. Plasma exiting from the nozzle

Furnace Benefits

A furnace incorporating such a plasma torch generally displays the following benefits:

- Reduced Energy Costs - Energy efficiencies of 0.2kWhr/lb for melting with no emissions
- Improved melting because of ultra-clean metal
- Clean melting with dross values less than 0.5%
- No requirement for nitrogen, argon or chemical fluxes - significantly reducing operating costs with favorable environmental impact

- Extremely small equipment footprint as shown above in Fig. 1
- Quiet operation - zero noise - much lower than typical, conventional plasma systems
- High energy density - nearly four times compared to the standard

Although the main method of use is to add the torch to an existing furnace in a retroactive manner, the mid-temperature range convective-plasma device can also be used as the only heat source in a new furnace. Such a Plasma Aluminum Melting (PAM) furnace (a typical design is shown in Fig. 2) is a possible method to deal with the next generation melting problems, allowing energy rates as low as 0.198 kWh/lb, as compared to induction melting energy rates of 0.345kWh/lb. The PAM can be constructed as an automated furnace, which allows quick charging, rapid melting, pouring and disposal of dross. The combined effects of conduction from the hearth, forced convection from plasma and radiation contribute to the concentration of heat. Such a furnace may be constructed for a variety of melting needs, ranging from ingot melting, sprue melting and scrap melting for recycling. Several custom footprints are possible. In addition, there is no noise or foul burning-gas smell. Table 1 shows typical melting parameters observed for a 23kW system.

Energy Density

Conventional aluminum furnaces generally do not focus on energy density, as the numbers are low for wire-wound, gas-fired and silicon-carbide-powered aluminum furnaces. High energy densities of the plasma-fired furnace, however, allow more heat to be transferred to the charge and less heat to the outside. A furnace with high energy density is desirable, thus energy density is important for energy conservation as well as for reducing the footprint of the furnace. A typical electric-resistance melting furnace exhibits an energy density concentration of 64,557 BTU/ft³, as opposed to the new PAM furnace with 269,146 BTU/ft³, for equal volume of hot zones. The PAM furnace has

four times higher energy per unit volume compared to an electric-resistance furnace, thus making it a unique furnace with highly concentrated power.

In addition, as the power density (i.e. energy density per unit time) is increased in conventional furnaces, the melt rate tapers off as shown in Fig. 3. In contrast, for furnaces that have a mid-temperature range convective-plasma device, the melt rate remains high because of the enhanced heat transfer the plasma provides.

Why does this happen? The reason lies in the fact that the heat-transfer coefficient increases with the gentle plasma even where the convection velocity is small. Figure 4 shows the basic plasma heating and nitrogen cover principle. Figure 5 is a plot from Reference 2, which shows the enhancement in the surface heat-transfer coefficient to the charge.

Economic Comparisons

For economic comparisons between the several techniques used for aluminum melting, the factors to be taken into account are: the cost of equipment and installation, and the operating costs, which depend on the utility costs in the area, the energy efficiency of the equipment chosen,



Fig. 2. A furnace chamber with continuous loading and unloading can be constructed with the PlasmaAirTorch™ as the only heat source. A cut-away from such a furnace is shown.

Table 1: Typical melting results from a 23kW aluminum melting furnace. The furnace had a footprint of about 36 square inches.

Energy to melt	0.2kWhr /lb
Dross/ Total Metal Loss	~0.5% or lower depending on alloy
Melt Rate	~12.7 g/s (compare with 3g/s for conventional) ~1 Ton / day for 23kW.
Energy Concentration	269,146 BTU/ft ³ (~10 ⁷ kJ/m ³)

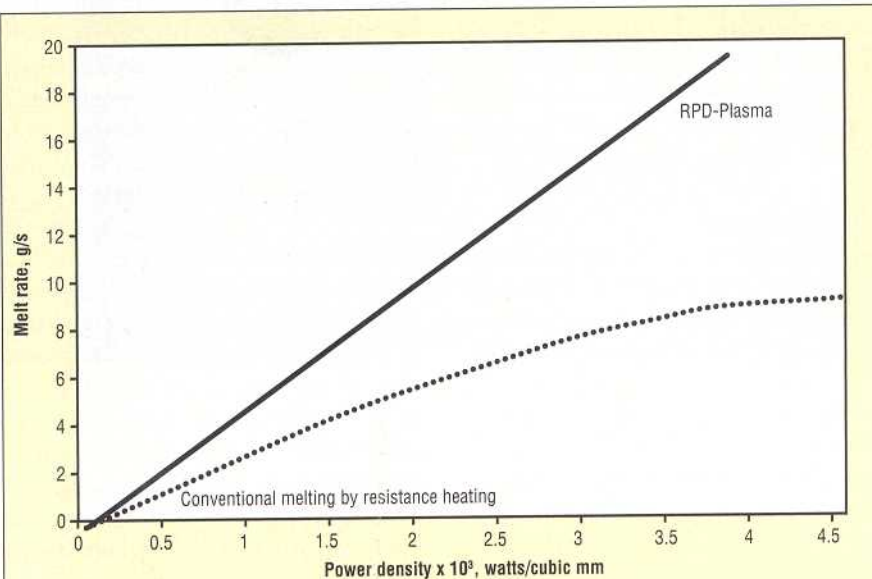


Fig. 3. Conventional furnaces are unable to create heat on the charge and their efficiency falls off. Plasma-assisted furnaces automatically have high power densities and heat transfers directly to the part.

the quality requirements of the finished casting and the metal losses (dross) to be expected as a result of the melting process. In addition, there is a cost associated with regulation and comfort factors, such as EPA considerations, heat, noise, and air pollution, and the casting size range and the weight of metal required per day, and associated storage and manpower costs.

Installation costs of electric resistance and fossil-fuel-fired furnaces

are comparable. It is not practical to hypothesize a specific example, as there are too many possibilities to take into account. In general, fossil-fuel-fired furnaces require fluing, blower equipment, and in some cases heat exchangers (for preheating combustion fuels). On balance, however, power controls often result in a slightly higher investment for electric operations. Another widely used method for melting is the induction furnace. While induction

furnaces cost more than resistance furnaces, their production rates are generally much higher. An operating cost comparison is presented in the table below to illustrate the relative expenses for a hypothetical aluminum melting operation. Metal loss includes dross plus flue loss. The most significant operating cost consideration is not only in the relative cost of the utilities (i.e., gas, oil, electric etc.), but the relative metal losses to be expected and

Table 2: A summary of the qualities of most conventional and the new Plasma Aluminum Melt furnaces

Furnace	Main advantages	Energy used (kWh/lb)	Metal loss dross	Energy efficiency	Main complaints	Remedy
Indirect fixed crucible	<ul style="list-style-type: none"> Simple Low cost of capital equipment Easy to maintain Gas is cheap 	3,300 BTU/lb (0.9969 kWh/lb)	~3-8%	13%	<ul style="list-style-type: none"> Low pot life High energy loss Emissions Noise 	<ul style="list-style-type: none"> Leave a heel No remedy No remedy No remedy
Direct fixed (open flame)	<ul style="list-style-type: none"> Very simple Low cost Easy to maintain Gas is cheap 	4,000 BTU/lb (1.172 kWh/lb)	~5-12%	11%	<ul style="list-style-type: none"> Low pot life Very high energy loss High uncontrolled emission Very high noise 	<ul style="list-style-type: none"> Leave a heel No remedy No remedy No remedy
Sloping dry hearth	None	3,000-5,000 BTU/lb (0.879-1.465 kWh/lb)	~5-12%	9-15%	<ul style="list-style-type: none"> Noise Very high melt loss High energy loss Emissions 	<ul style="list-style-type: none"> Improve flame impingement Charge better scrap No remedy No remedy
Wet bath reverboratory	None	3,000 BTU/lb (0.879 kWh/lb)	3-5%	15%	<ul style="list-style-type: none"> High energy loss Emissions/flue 	<ul style="list-style-type: none"> No remedy
Electric radiant reverboratory	<ul style="list-style-type: none"> Cold start possible No flue No agitation No noise 	820 BTU/lb (0.2403 kWh/lb)	1-3%	54%	<ul style="list-style-type: none"> Very high currents Very small sizes High cost of electricity Pot life suspect if one element burns 	<ul style="list-style-type: none"> No remedy Three base No remedy Constant monitoring
Electric induction channel type	<ul style="list-style-type: none"> Rapid melting Cold start possible 	0.29 kWh/lb	High	45%	<ul style="list-style-type: none"> Too much mixing of dross Very expensive equipment & large space Only for holding furnace Non-metallics in channels High dross Electromagnetic field Noise 	<ul style="list-style-type: none"> Use only when holding furnace needed
Coreless induction melting	<ul style="list-style-type: none"> Rapid melting Cold start possible 	0.29 kWh/lb	High	45%	<ul style="list-style-type: none"> Very expensive equipment High dross Electromagnetic field Noise Large space needed 	<ul style="list-style-type: none"> Use fluxing covering salts extensively
Plasma aluminum melting	<ul style="list-style-type: none"> Extremely rapid melting Highly energy efficient Excellent for ingot, sprue and scrap melting Least iron contamination with sprue melting No chemistry adjustment since Zn, Mg, Li will not have time to vaporize No noise No emissions Less space 	0.20 Kwh/lb	Insignificant-ly low, <1%	65%	<ul style="list-style-type: none"> No significant drawbacks 	

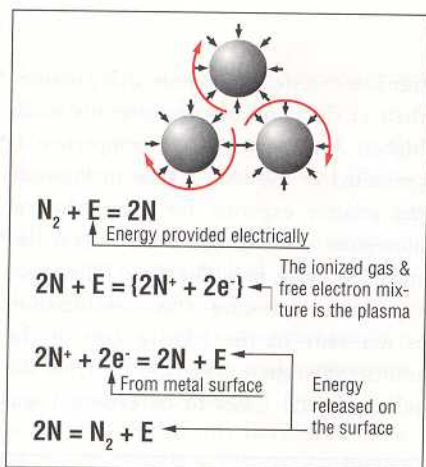


Fig. 4. The basics of plasma heating

the reliability index. Electric resistance melting yields are high, while metal losses from fossil-fuel operations may be as high as 8%. When taking into account the metal loss, the current, as well as the projected metal cost at the spout, should be used in making investment decisions. Utility

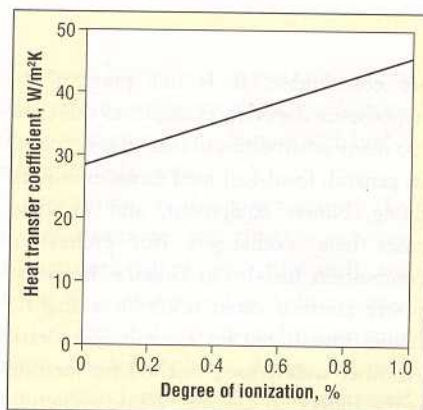


Fig. 5. Variation of heat-transfer coefficient with the degree of ionization for aluminum (a similar result is expected for all metals)

costs vary widely in different localities. For example, gas prices can range from \$2.50 to \$4.86/MCF, while electric costs can range from \$0.032/kWhr at off-peak times to \$0.08/kWhr or more. Theoretical melting for aluminum is 445BTU/lb. Efficiency is calculated in the table below where mass is

the melted mass:

$$\text{Energy Efficiency (\%)} = \left\{ \frac{\text{Mass Energy (actual)}}{\text{Mass Energy (theoretical)}} \right\} \times 100 \quad (1)$$

Conclusion

Based on the results obtained to date, the following energy and environmental benefits are noted from using the mid-temperature range convective-plasma device for aluminum processing.

Measured Energy Saving

The improvement in energy efficiency over using the convective heat source furnace is calculated to be approximately 73-82%.

Environmental (waste stream) Savings

In addition to this, the PAM offers many other non-measurable savings, such as elimination of harmful emissions and noise (no noise) and increase of productivity. Since PAM replaces gas/oil burners with ionization units, we anticipate that the harmful emissions (e.g. CO, CO₂, NO_x, etc.) associated with existing gas/oil-fired furnaces will be totally eliminated.

Productivity and Profitability

A small footprint furnace or a retrofit to an existing furnace is able to considerably enhance the melt rate (four times) and eliminate labor time with disposing waste.

References

1. Web site <http://www.mhi-inc.com/PG4/UPAT105.html>
2. V. Rajamani, R. Anand, G. S. Reddy, J. Sekhar, and M. A. Jog in Metallurgical Transactions B. 2006 in-print. (expected in September issue).

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