Recovering Aluminum via Plasma Processing

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A process based on the use of a plasma system for recovering aluminum from dross, beverage cans, and aluminum scrap has been developed. The plasma process is clean, and there is no need for the addition of any compound, such as salt. In principle, a higher recovery rate of aluminum is attainable, since no oxidation of the aluminum occurs during the process. An economic analysis shows that the operating costs for the plasma system are at least 23% cheaper than for the traditional process using air/gas or ail/oil burners; the plasma process also does not generate either of the common residues produced by the burners. The maintenance costs of the plasma process are also lower than that of the traditional process. Overall, the plasma system is cheaper, cleaner, and easier than the oil/gas burner technology when recovering aluminum from dross, beverage cans, and scrap.

INTRODUCTION

Aluminum production worldwide in 1996 reached almost 20 million tonnes.[1] Aluminum is extensively used in the packaging and automobile industries, as well as for construction and manufacture of such goods as ladders, chairs, and other items.

The aluminum recycling industry accounts for almost 30% of aluminum consumption worldwide; beverage cans, scrap, dross, borings, and scalper chips are remelted and sold to primary aluminum producers or to secondary transformers. The push toward aluminum recycling is based on significantly lowering energy consumption as compared to producing aluminum (0.7 kWh/kg instead of 14 kWh/kg), saving natural resources, avoiding the generation of 4 kg of waste red mud per kg of primary aluminum produced, reducing the amount of wastes that need to be landfilled, and keeping the price of aluminum competitive.

Aluminum recycling is based on a thermal process—aluminum-rich residues are fed into a furnace operating at approximately 700°C. The high temperature and long residence times guarantee the melting and sterilization of the material, particularly in the case of food packages. Different types of furnaces traditionally used for metallurgical applications can be used for the process, including reverberatory furnaces with charge wells or feeding directly to the hearth and oil/gas burners to supply the necessary energy, rotating furnaces with burners installed at one end, and induction furnaces used only for remelting clean and finely divided scrap.

The type of furnace used is normally based on the material to be treated. The three main classes of aluminum-rich materials recycled are aluminum beverage cans, aluminum dross, and aluminum scrap.

Aluminum beverage cans are normally processed in two different types of plants. Large, dedicated units capable of treating around 300,000 t/y operate with a decoating section (thermal or chemical). The necessary energy for the process is provided by burners, and a reverberatory-type of furnace is normally employed. Smaller units using rotating furnaces with burners that are also capable of treating other aluminum-rich residues, such as dross, are used as well, with a production between 10,000 t/y and 30,000 t/y.

Aluminum dross, with an aluminum content of around 50 percent and the remaining consisting essentially of alumina, originates from the primary production of aluminum; it represents about 2% of production. It is recycled in rotary furnaces with burners similar to the ones used for cans.

Scrap includes clean, heavy gauge scrap as well as fine, oil-contaminated pieces. The remelting of the former is normally conducted in reverberatory furnaces or, alternatively, in induction furnaces. The finely divided scrap is particularly difficult to remelt even in the rotating units due to the large surface area, causing the oxidation of part of the charge.

A common practice for most of the processes that use burners for heating the material is the use of salt (60% NaCl and 40% KCl) to prevent the oxidation of the charge. The salt forms a coating above the molten metal and protects the aluminum from excessive oxidation; it also collects the dirt and contamination of the material. The amount of salt used in the process varies with the material being melted, the type of furnace used, and the operating conditions. Normally, 10–40 kg of salt is added for each 100 kg of aluminum-rich residue fed in the furnace. The salt is skimmed off after use and disposed in a landfill.

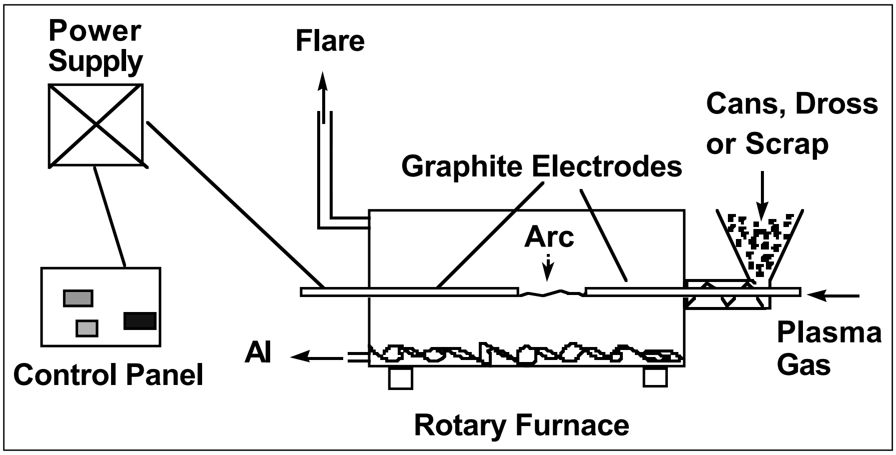

Figure 1. A schematic of the plasma process.

These technologies present some technical and environmental problems. The large plants for recovering aluminum from beverage cans can only treat those materials, and the large volume of gases

Table I. The Mass Balance Results for the Gas Burner and Plasma Processes

Process	Aluminum Fed (kg/h)	Air (kg/h)	Argon (kg/h)	CH_4 (kg/h)	Salt (kg/h)	Offgas (kg/h)	Residues (kg/h)	Efficiency (%)
Gas Burner	133	350	0	21	25	354	75	79
Plasma	111	0	0.65	0	0	3.4	8.3	95

generated in the process can contain some toxic compounds (particularly, dioxin and furans) due to the chlorine and carbon present in the paint. The large plants are economically feasible only if treating large quantities of cans (more than three billion cans yearly), demanding not only the construction of large and expensive plants, but also good logistics for buying and handling that volume of material. The cans typically travel long distances from the collection points to the plant, increasing the operating costs. The smaller units, more flexible in terms of investment, location, and material to treat, present serious environmental problems due to the use of salt and, in some cases, suffer considerable melt loss due to oxidation.

New technology based on the use of a plasma system has been studied recently by different groups (Alcan, Hydro Quebec, Instituto de Pesquisas Tecnológicas do Estado de São Paulo [IPT], and others). The processes developed vary on the type of furnace used (reverberable or rotating), as well as on the type of the plasma system used (plasma torches or graphite electrodes). In this article, the plasma process developed at IPT for treating residues containing aluminum is described. Results for the remelting of fine scrap are given, and technical and economic analyses, including a direct comparison between a small unit using a rotating furnace with burners and the plasma system developed at IPT, are presented.

ALUMINUM RECOVERY PROCESSES

Rotating Furnaces with Burners (Small Units)

This process utilizes a rotating (or reverberable) furnace and oil/gas burners to heat the charge up to 700°C. Air is allowed into the furnace for the operation of the burners; the offgases are not always treated before they are exhausted. The furnace can remelt beverage cans, dross, or scrap, and it is a common practice to add salt (NaCl or KCl) to the charge in amounts varying from 10–40 kg per 100 kg of charge to prevent oxidation of the aluminum (burners need oxygen in order to operate). The salt also promotes the agglomeration of the aluminum drops into the melt at the same time. The salt is removed from the furnace prior to the tapping of the furnace and is recycled to the next heat. After a few heats (an average of three), the salt is removed from the furnace and discarded.

This technology has several drawbacks, including low recovery rates (part of the aluminum is oxidized even with the use of the salt); the controlled discarding of the used salt, which is considered to be a toxic material, Class I; the potential harmfulness of the use of salt to the workers close to the furnaces; corrosion of the equipment by the salt, forcing constant replacement of refractories and metallic parts of the system; the energy inefficiency of the process (part of the heat is used to melt the salt, which also forms a thermally insulating layer, preventing part of the heat from the burners to reach the molten metal); and high operating costs due to buying/discarding of the salt, equipment maintenance, and melt loss due to oxidation.

Plasma Furnace

The process for remelting aluminum-rich residues developed at IPT is based on a plasma technology. The furnace used was similar to the rotary one described with a plasma system installed in place of the burners. The plasma system provides the energy for the process.

In general terms, thermal plasmas can be understood as an ionized gas at elevated temperatures (5,000–20,000 K). The plasma is normally generated in torches or by using graphite electrodes. An electric arc is maintained between the electrodes (metallic, in the case of the torch, or graphite), and any gas at ambient temperature can, in principle, be injected into the torch and will interact with the electric arc. The electrons of the arc transfer part of their kinetic energy to the gas, increasing its temperature and ionizing it at the same time. The gas at the exit of the torch is called the plasma jet, reaching the high temperatures mentioned. Plasma systems have been used in different applications such as metallurgy, steel making, the production of advanced materials, the destruction of toxic wastes, and others.[2–4]

In this work, the plasma system consisted of either a plasma torch or two graphite electrodes. Results obtained were similar, so only the graphite electrodes system is described here. A direct current system was used to provide the electric arc between the graphite electrodes and to generate the plasma. A schematic representation of the

Table II. The Power Balance of Gas Burner and Plasma Processes

Process	Gas (kWh)	Electricity (kWh)	Loss Conduction (kWh)	Loss Gases (kWh)	Loss Residue (kWh)	Loss Plasma (kWh)	Loss Rectification (kWh)	Energy Aluminum (kWh)	Efficiency (%)
Gas Burner	280	0	51	184	16	0	0	29	10.4
Plasma	0	79	32	1	2	5	10	29	36.7

Table III. An Economical Analysis of the Processes

Equipment	Burner Furnace ($)	Plasma Furnace ($)
Equipment	280,000	310,000
Installation	42,000	46,500
Total	322,000	356,500
Annual Operating Costs		
Equipment	106,000	63,000
Labor	500,000	450,000
Energy	184,000	173,000
Scrap	933,000	785,000
Plasma Gas	0	13,000
Salt	25,000	0
Landfill	164,000	0
Total	1,912,000	1,484,000

system can be seen in Figure 1.

A continuous feeding system was developed to allow uninterrupted operation of the furnace. The atmosphere inside the furnace was controlled in order to avoid the presence of oxygen inside the vessel; hence, no salt was needed. The developed process is environmentally clean (no residues are generated in the process) and can, in principle, provide higher efficiency in recovering the aluminum content in the charge.

RESULTS OF THE BURNER AND PLASMA PROCESSES

The gas burner and plasma processes were compared, using the rotating furnace as an example of gas burners. A comparison of the experimental results for the remelting of fine scrap aluminum contaminated with oil (5% of oil in weight) between both systems are presented here; similar conclusions were reached for the other types of materials considered (i.e., beverage cans and dross). The values for the plasma process were obtained using the system developed by IPT; the values for the traditional burner system were obtained from literature,[5–8] along with consideration of the system described (considering the dimensions of the rotating furnace used for the plasma experiments).

Mass Balance

In the plasma system, the oil contained in the scrap was partially volatilized and burnt in the flare; the part of the oil that did not volatilize agglomerated with fine aluminum drops and was removed from the furnace after a few heats.

Table I shows the mass balance results for the plasma process and the gas burner. Aluminum fed represents how much material had to be fed to produce 100 kg/h of aluminum; the offgases consisted of the gases injected (or reacted with the oil contained in the scrap, in the case of the burner) and the part of the oil contained in the material that volatilized (in the case of the plasma system). The residues generated in the processes consisted of salt and alumina for the burner and carbon and aluminum for the plasma process. The presence of 5% oil in the raw material was considered in determining the efficiency of the process.

The residues formed in the plasma process need further explanation. It was noticed that when using fine scrap contaminated with oil or beverage cans, a small part of the melted aluminum formed a powder with the fixed carbon that did not volatilize; the powder was not miscible with the remaining aluminum melt. The analysis of the powder indicated an approximate composition of 30% carbon and 70% aluminum. The potential exists for this powder to be used as an exothermic powder; no further effort was conducted to recover the aluminum contained in the powder.

Energy Balance

The energy balance of the processes is presented in Table II. The values were obtained for the 100 kg/h production of aluminum from scrap contaminated with oil

EXPERIMENTAL PROCEDURES

The plasma system consisted of a rotary furnace, plasma system, feeding system, flare, and rectifier and control.

The rotary furnace (1 m internal diameter, 1.5 m length) had a capacity of 100 kg of molten aluminum. The rotation speed of the furnace could be controlled and was maintained at 2–20 rpm. The refractory was 50% alumina and is available commercially.

A 200 kW designed plasma torch or two graphite electrodes (the electrodes had a central hole for the injection of the plasma gas) were used to generate the plasma. Each of the two graphite electrodes was positioned at one end of the furnace. An electric arc was maintained between the electrodes, providing the energy for the process. The length of the arc could be varied from 1 cm to 100 cm, according to the amount of material fed and the temperature desired. Argon was used as the plasma gas in most of the experiments; tests with carbon monoxide and nitrogen were also conducted. The gas-flow rate was monitored and controlled continuously using rotameters.

The material to be treated (e.g., cans, dross, and scrap) was fed into the furnace as received. The feeding system was developed specially for the process, consisting of a rotating screw, a system of mechanical seals, and gate valves. The system was robust and permitted the continuous feeding of material without allowing the inlet of air into the furnace. Approximately 5 kg/min. of material could be fed.

In the case of scrap contaminated with oil or beverage cans, there were volatile organic materials leaving the furnace. The offgases were burned in a flare; the system had an automatic valve for controlling the amount of air admitted in the flare for burning the gases.

A silicon rectifier or, alternatively, a thyristor rectifier with a maximum output of 100 kW and 500 kW, respectively, was used to provide direct current for the plasma system. The arc current and voltage were continuously monitored and registered into a portable computer through a data-acquisition system. The inside and outside temperatures of the furnace were continuously measured using thermocouples and recorded into a computer.

During the procedures for treating different types of aluminum residues, the furnace was heated initially for approximately two hours in order to increase the temperature from ambient to around 700°C. The plasma gas used for the heating cycle was argon, at a flow rate of 6–10 l/min. The arc current was, on average, 400 A, and the voltage was 75 V for a 20 cm long arc.

Once the furnace had reached the process temperature (700°C inside the furnace), the aluminum residues were fed continuously into the furnace until the total charge reached approximately 100 kg. Depending on the type of material fed, volatile material left the furnace and was burned in the flare. The arc current during the process was reduced to between 250 A and 300 A, and the voltage varied between 120 V and 150 V (the arc voltage was a function of the amount of volatile material). The argon flow rate was kept at 6 l/min. during the melting cycle.

Once the entire charge had been fed, the furnace was kept rotating at 2 rpm at 700°C for 15 minutes. The furnace was then stopped and the aluminum melt tapped, resulting in ingots of 10 kg. About 10 kg of aluminum melt were always kept inside the furnace for the next heat. The feeding cycle started again, continuing the process. The average feeding-tapping cycle resulted in 100 kg/h of aluminum produced.

as indicated in Table I.

In Table II, the gas and electricity columns indicate the amount of energy from the combustion of gas or for the plasma system, respectively. Energy losses arose from conduction through the walls of the furnace; energy leaving the systems with the offgases; and, in the case of the plasma system, the losses from the rectification of the current and the plasma system (i.e., cooling of the electrodes). The energy that is useful for the melting of aluminum is indicated in the energy aluminum column; the efficiency of the plasma process was obtained from the ratio of the input energy and the useful energy.

Environmental Considerations

The two processes were also compared in terms of environmental impact. The process using burners generated around 75 kg/h of residues, while the plasma process generated only 8.3 kg/h, both of which have values for a production of 100 kg/h of aluminum from fine scrap contaminated with oil. The residues generated by the burner process must be treated or discarded in industrial landfills, since they are considered to be toxic materials (they contain salt, aluminum, and heavy metals from the alloys used in the aluminum). The residues generated by the plasma process could, in principle, be reused as an exothermic powder.

The amount of carbon dioxide generated in the traditional burner process (approximately 5.6 kg of CO_2) should also be considered for its possible impact on the environment. The offgases also need to be cleaned before they can be exhausted, and the cleaning of those gases can also generate liquid effluents that, once treated, generate more residues.

A COMPARISON OF BURNER VS. PLASMA PROCESSES

There is a considerable advantage in using the plasma process instead of the burner process in terms of aluminum recovery (Table I). The higher aluminum recovery for the plasma process results in a smaller quantity of residues generated; the residue generated has an appropriate composition (30% carbon, 70% aluminum). In the case of the burner process, the residues generated must be discarded in special landfills due to the potential toxicity of the heavy metals they contain. The refractories of the furnace have to be replaced approximately twice as soon as for the plasma system due to the presence of the salt, thus increasing the maintenance costs and the amount of residues generated.

The price of electricity is more than three times higher for the plasma process than the equivalent energy given by oil/gas burners ($0.06/kWh and $0.018/kWh for electricity and gas, respectively). The efficiency of the process offsets this difference, however, and the two systems have similar energy costs (Table III). The main losses of the burner system come from the offgases, which, in considerable amounts, need to be treated before they can be exhausted to the atmosphere, increasing the operating costs of the process.

An economic evaluation of both processes for the production of 500 kg/h of aluminum coming from oil-contaminated scrap was conducted. The production rate chosen (rather than 100 kg/h) was an attempt to reflect the conditions of a small, but possibly real, remelter. The values of energy consumption, the generation of residues, and others were taken from Tables I and II, considering a production of 500 kg/h. All of the values given reflect prices practiced in Brazil, but these are not very different from the ones in other areas, such as North America and Europe.

In Table III, the annual costs of the equipment take into consideration five years for the amortization of the burner system (with 12% interest per year) and ten years for the plasma system (12% year). This difference is due to the constant requirement for burner process maintenance due to the use of salt, which attacks the refractory, the furnace, and accessory equipment (particularly the gas-cleaning system). The plasma system needs, in principle, one less person than the burner system (less maintenance); this is reflected in the lower cost of labor for the plasma system. The costs of raw material (scrap) were considered to be $0.19/kg; the different total values for the scrap for both processes is a reflection of the higher efficiency of the plasma process as indicated in Table I. The costs for landfill considered $60/t of residue generated; this value would, in reality, probably be higher because the residues from the burner process are considered to be toxic, and, therefore, the use of special or industrial landfills is mandatory. The residues from the plasma system were considered to be completely recyclable (exothermic powder going to metallurgical applications), but the revenues coming from the sale of the residues are not considered.

From these calculations, the plasma process is at least 23% cheaper than the burner process; this calculation did not take into consideration the possible revenues from the sale of the exothermic powder produced in the plasma system and the probable higher costs for discarding the residues of the burner process. The costs for producing aluminum from scrap contaminated with oil, which is based on the values given in Tables I, II, and III, are approximately $0.52 and $0.41 per kilogram of aluminum produced.

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