TECHCOMMENTARY

PLASMA ARC TECHNOLOGY

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An Electric Energy Tool for High-Temperature Materials Processing

Introduction

Over the past 40 years, engineers worldwide have developed many materials processing applications using plasma arc heaters. Early applications at low power levels of 10 - 20 kW were for the cutting and welding of metals and for plasma spraying of metal and refractory powders to form protective coatings. These are now well-established commercial processes. Continued developments are being made for the surface treatment of metals (phase transformations for hardening, carburizing, nitriding) and for metal overlays. Present research efforts at low powers include the synthesis of diamond films as well as the production of superconductive and engineering ceramic powders.

During the 1960s, plasma arc heaters were developed at power levels of 500 kW up to 35 MW for aerospace materials testing. Subsequent plasma heater developments have resulted in many high-power applications for materials processing. Today, industrial-worthy plasma arc systems are available for extended reliable operation at high power and current levels. Commercial breakthroughs in technology include simple physical tasks, such as heating of molten steel in continuous casting tundishes for temperature control using 1 - 4 MW plasma heaters. Complex multiphase chemical reaction systems with high specific energy requirements, such as ferrochromium production by carbon reduction of chromite ore fines, are being processed at power levels up to 30 MW.

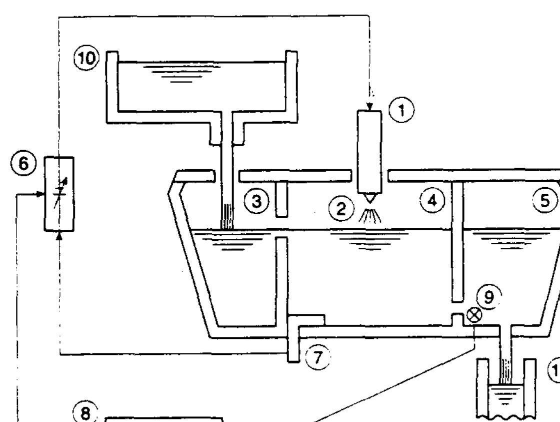

Figure 1 Plasma Tundish Heater and Control System

What are Plasma Arc Heaters?

All electric arcs are plasmas. Plasma simply refers to the presence of ionized gases. Plasma arc heaters are electrical resistance heaters where the resistive element is the electrically-conductive partially ionized gas between two electrodes. Whereas plasma arcs occur in nature as sudden lightning discharges, plasma arc heaters provide a continuously-controlled electrical arc discharge.

Although the arc discharge can be controlled by magnetic and mechanical means, the key design feature of plasma arc heaters is the controlled feed of gas to the arc environment. The gas can be either reducing (e.g., hydrogen), oxidizing (oxygen) or inert (argon).

Heaters can be designed for both low and high gas-flow rates. The gas can be used to convey fine solids, liquids, or additional gases into the arc-heated zone for physical transformations and chemical reactions. This controlled flow of various gases enhances the versatility of plasma arc heaters when compared to conventional electric arc furnaces with "free burning arcs" and no gas control features.

The core temperature of the plasma arc can range from 4,000 to 20,000°C (7,200°-36,000°F). The working temperature of the bulk gas, depending on the gas flow rates and the heater design, is about 2,000 - 3,000°C

(3,600°-5,400°F). The high temperature of the arc and the working gas plus heat transfer at the arc root attachment area result in heat fluxes about 10-50 times higher than oxygen - fuel flames.

Most plasma heaters operate on direct current, with "nontransferred" and/or "transferred" arcs. For nontransferred operation the gas phase is the only working resistive element, Figure 2a. The arc can be "transferred" attaching directly to a workpiece (e.g., an object to be cut, welded, heated, melted, reacted, etc.), as shown in Figure 2b, with resistive heating of both the gas phase and the workpiece in series.

Nontransferred arc heaters are used when it is desirable to heat the gas phase, such as for gas phase reactions (e.g., production of acetylene from natural gas) and for countercurrent solids — gas contact in shaft heaters, melters (cupolas), and reactors (blast furnaces). These heaters typically consist of water-cooled cylindrical copper electrodes and operate up to 2,000 amperes and 6,000 volts with high flow rates of a reactive gas.

Transferred arc heaters are useful for the bulk heating of solids and melts and where the gas phase is not a principal reactant but can be important as an inert shield. The gas flow rates are typically very low which can be important for controlling vapor phase reactions and condensation phenomena. Transferred arc heaters typically operate at up to several thousand amperes (as high as 100,000 A with graphite electrodes) and a few hundred volts. The workpiece is one electrode; shown as the anode (+) in Figure 2b. The gas phase electrode, or cathode (-), can be a water-cooled copper cylinder or a refractory metal button (e.g., thoriated-doped tungsten), or it can be a hollow graphite electrode without water cooling. The hollow passage can be used for the direct introduction of gas and fine solids into the arc environment as shown in Figure 5 for the reduction of chrome ore fines for ferrochromium production.

THE PLASMA ADVANTAGE

The unique advantages for the application of plasma arc technology include:

Gas environment control
Gas-flow rate control
Fine particle feed capability
High temperature
High energy fluxes
Rapid quenching
No products of combustion

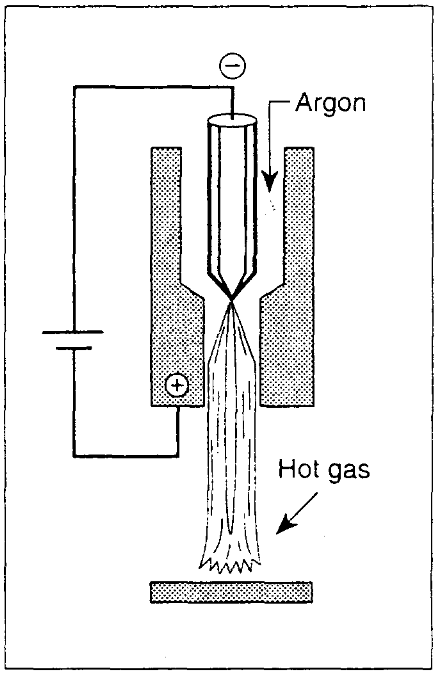

Figure 2a. Nontransferred Arc

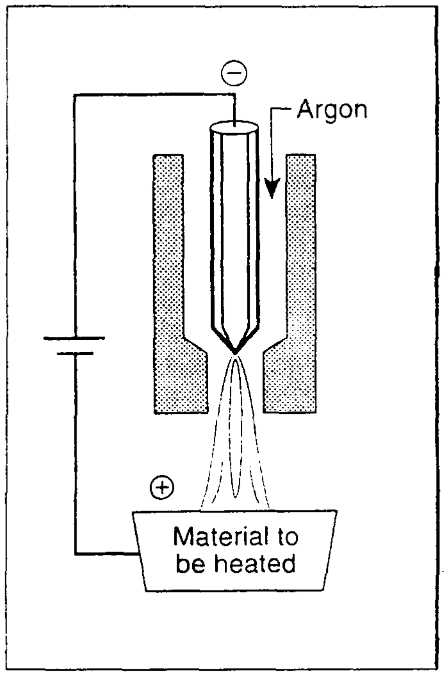

Figure 2b. Transferred Arc

OTHER PLASMA AND ELECTRODELESS ARC DISCHARGES

In addition to arc discharges between electrodes it is possible to sustain plasma discharges by high-frequency powered induction coils. These electrodeless induction-coupled plasmas (ICP) have the unique capability of producing an ultraclean arc and plasma with no contamination. These systems, which can operate at atmospheric or reduced pressures, are ideal as a heat source for chemical analysis instruments, and also for powder treatment. Conventional systems operate up to about 30 kW, but developmental ICPs have operated on air at 900 kW.

Plasma arc discharges are typically produced at normal pressures. Plasma discharges also can be produced at low pressures such as the familiar fluorescent lamp. Low-pressure discharge devices are in wide commercial use in microelectronic fabrication for etching patterns in integrated circuits.

CMP's activities have been focused on the development of plasma arc processes rather than on induction-coupled or low-pressure plasmas.

Center for Materials Production Role

In 1988, CMP published "A Survey of Thermal Processing Research Facilities" as an aid to planning research activities. In March 1990, CMP organized the first EPRI-sponsored plasma symposium on "Industrial and Environmental Applications of Plasma" attended by specialists from plasma vendors and developers, as well as from electrical utilities and industry.

CMP has supported laboratory, pilot plant, and industrial scale plasma activities for treating electric arc furnace dust and specialty steelmaking dusts, smelting of silicon metal and ferrosilicon production from taconite fines, melting of aluminum scrap, melting / separation of aluminum from scrap melter dross, and the heating / refining of steel ladle melts. In addition, EPRI has funded the development of the plasma-assisted cupola for iron melting and recycling of mill scale (iron oxide).

Applications of Plasma Arcs

The plasma processing of gases, liquids, and solids covers a wide range of applications including both physical and chemical changes with increasing specific energy requirements. The least energy-demanding system is that of heating solids, liquids, or gases, with no change of state. For a change of state, greater energy inputs are needed to melt solids and then to vaporize liquids. The most demanding are complex chemical reaction systems with changes of state such as vaporization of liquids produced from solid feeds. All of these systems have been successfully demonstrated with the use of plasma arc technology.

A complete plasma system will include a plasma heater, a processing unit (e.g., furnace, reactor, spray chamber) and requisite auxiliary equipment, such as the power supply, working gas, reactant feeds, product collector, and cleaning and cooling of the product gas.

Heating, Melting, and Remelting

Heating of steel melts in tundishes and ladles

In 1987, a 1 MW tundish heater was installed at Nippon Steel's Hirohata Works. By mid-1991 there were 12 plasma installations worldwide for temperature control of steel in continuous casting tundishes. These units range in power level from 350 kW to 2.4 MW for tundish melts of 5 tons to 80 tons, respectively. The unit, as shown in Figure 1, equipped with a sensor in the melt, can control the steel temperature to ± 1° C of the target temperature. Plasma tundish heating has several advantages including (1) increased steelmaking vessel (oxygen converter, electric arc furnace) refractory life due to lower steel tap temperatures,
(2) improved steel quality, e.g., prevention of center segregations for high-carbon steels such as hard-drawn wire,
(3) higher yields due to elimination of strand freeze-off and less mold powder related product defects.

Plasma heating of steel ladles has been developed industrially on melts from 30 - 220 tons and heaters from 1 - 15 MW. CMP has funded the development of heating and refining of foundry ladle melts.

Melting and Remelting of High-Alloy and Refractory Metals

High-Alloy Steels

The first large-scale industrial application of scrap melting was in 1973 in Freital, E. Germany at 20 MW with 30-ton heats of alloy steel. The plasma advantage was the ability to melt with inert argon to prevent reoxidation and yield loss to the slag of expensive alloys such as chromium, and molybdenum.

FeMn , FeCr

In South Africa the plasma remelting of ferroalloy crush fines of ferromanganese and ferrochromium in 4 MW and 14 MW plasma furnaces, respectively, was initiated in 1983.

Titanium

United States-fostered plasma technology is used at five locations for "inert gas"— melting and remelting of titanium scrap and sponge, see Figure 3. Plasma heaters range from 300 kW to 2.25 MW. In one case Oregon Metallurgical Corp. melts titanium scrap and sponge using an 800 kW Retech heater to produce 6 million pounds per year of titanium electrodes for remelting. A unique cost saving feature of this installation is the inert gas recyle system.

Reclaiming of Metals from Scrap Materials and Residues

Reclaiming of metals from consumer discards and industrial residues by plasma melting is attractive due to the low gas flow rates which minimize off-gas cleaning and handling systems in comparison to combustion heating

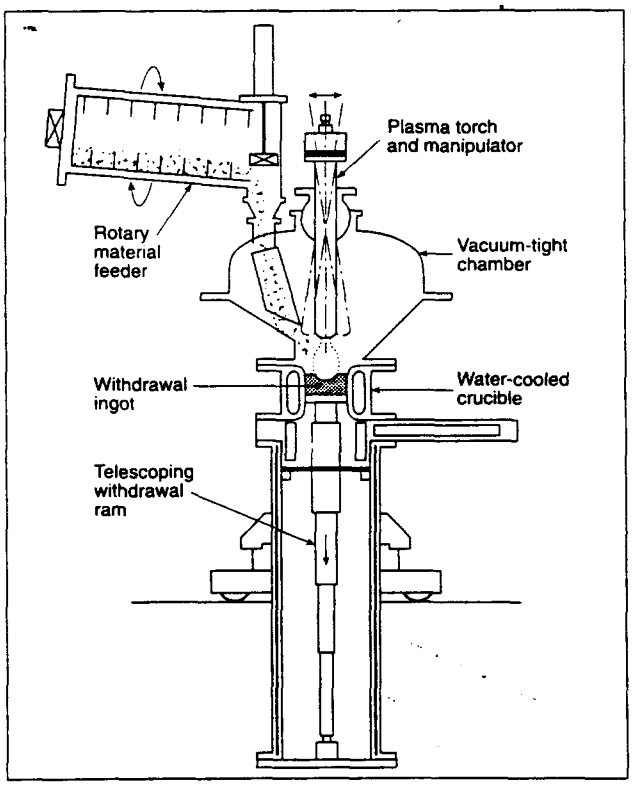

Figure 3 Plasma Titanium Melting

systems. In addition, the higher temperatures and heat fluxes increase equipment throughput and a plasma inert gas minimizes metal reoxidation.

Iron

The ability to lower the volume of gas flow is the plasma advantage for the General Motors foundry plasma-fired cupola in Defiance, Ohio. The cupola uses six 1.5 MW Westinghouse plasma torches as shown in Figure 4. In conventional coke-fired cupolas the plant-generated scrap chips, and borings would be swept out due to the high flow rates of the combustion off-gases. This development, commercialized in 1989, was funded in part by EPRI. In a related development in France, a 2 MW Aerospatiale heater has been used since 1989 to increase the blast air from 400 to 1,000°C (750°-1,800°F)on a Peugeot cupola resulting in decreased coke consumption, reduced dust emissions, and increased cupola capacity.

Platinum

Since 1984 a 3 MW Tetronics R&D plasma furnace has reclaimed platinum from automobile emission catalysts by a simple melting process at the 70,000 oz./year capacity Multi-Metco facility in Anniston, Alabama.

Aluminum

In the remelting of aluminum scrap large quantities of dross are generated which contain substantial quantities of aluminum droplets. An experimental program by Hydro-Quebec using a plasma-fired rotary kiln for aluminum recovery from dross has been commercialized by Alcan using a Plasma Energy Corporation (PEC) heater. The Center for Materials Production has funded further development of plasma processes to treat aluminum drosses containing lead and cadmium contaminants.

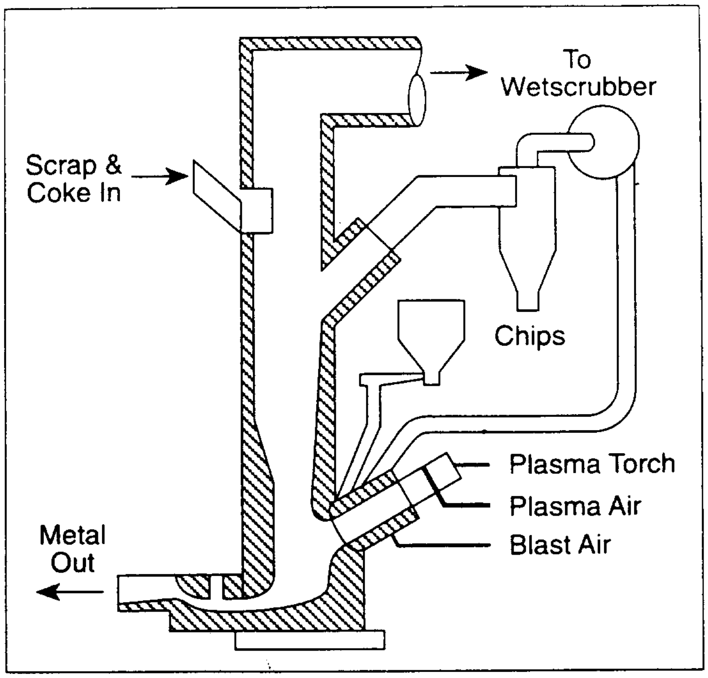

Figure 4 Plasma Cupola

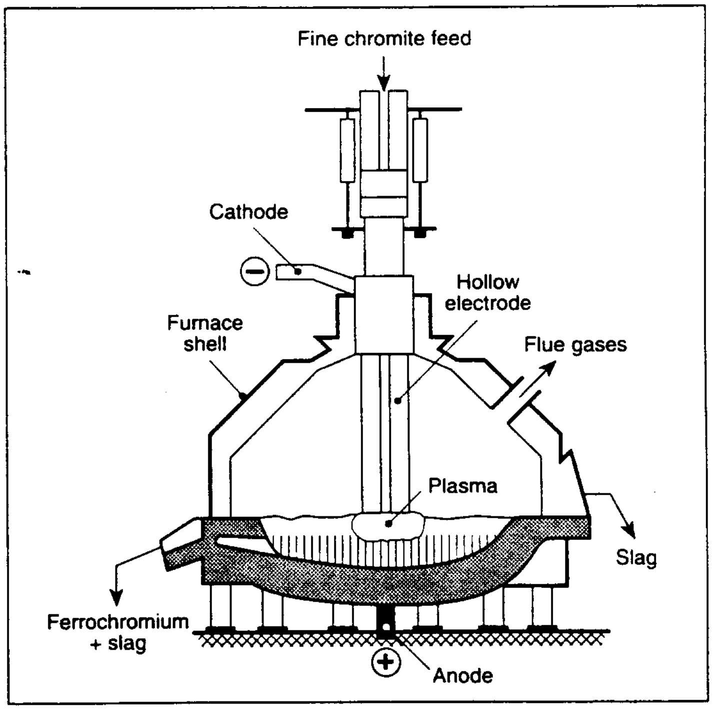

Figure 5 Plasma Ferrochromium Production

Smelting of Ores

Chromite ores

The ability to smelt low-cost friable chromite ores as fines has been one of the most successful applications of plasma systems. In December 1983, a 14 MW dc hollow graphite electrode transferred-arc ASEA Brown Boveri/ Mintek system was installed in South Africa for Middleburg Steel and Alloy. In 1989, this installation, Figure 5, was increased to a 30 MW furnace with smelting of chromite ore and ferrochrome crush fines fed through the hollow electrode. Significant development work was required for the auxiliary systems for fines feeding as well as for off-gas removal.

In 1986, two shaft furnaces, each equipped with four 6 MW nontransferred SKF plasma gas heaters, were installed for smelting of chromite ores in Sweden. This facility which also required development work on the ore feed system operated satisfactorily by 1988, but was shut down in 1990 due to unfavorable chromium prices.

Manganese ores
In France in 1984, three 1.5 MW nontransferred Aerospatiale plasma gas heaters were retrofitted to a ferromanganese blast furnace to replace coke as fuel during electrical off-peak periods. This was increased to eight 1.5 MW heaters in 1986.

Iron ores
In 1987, six 2.0 MW Aerospatiale heaters were retrofitted to increase the blast temperature of an iron blast furnace at Lorfonte, Lorraine, France.

In 1981, a SKF system with three 2 MW plasma gas heaters was used to produce a reduction gas to produce metallized pellets. The SKF shaft reducer in Hofors, Sweden was decommissioned in 1985 due to a switch to a 100% scrap feed for the electric arc steelmaking furnace.

Treatment of Dusts

Plasma systems for treating dusts have substantial economic potential for the disposal of hazardous materials. In addition, there is a possible credit for reclamation of useful metals from the dusts.

Zinc, Lead, Cadmium-bearing electric arc furnace dusts In 1989, two Tetronics R & D systems of 2 and 3 MW were installed in the United States for zinc recovery from EAF dusts with the production of a nontoxic slag. This development was cofunded by CMP and 30 steel companies. Further plant modifications have included the use of hollow graphite electrodes. See Figure 6.

Chromium, Nickel, Molybdenum-bearing steel plant dusts In 1989, a 3 MW Tetronics system was installed for British Steel in Sheffield to smelt and recover the alloy values in dusts collected from steel refining vessels. A SKF system in Sweden is smelting stainless steel dusts in a shaft furnace fired by three 6 MW heaters.

Powder Synthesis

A major commercial area for plasma arc systems has been the production of powders, such as titanium oxides and zirconium oxides. Titanium oxides were produced by PP&G in the late 1960s using a one MW Linde arc heater. Tioxide (UK) presently produces not only TiO_2 but other high-tech ceramic powders including nitrides of titanium, silicon, and aluminum, as well as yttria-coated zirconia. These powders are synthesized by gaseous reactants in nontransferred plasma heaters. Commercial powders are also produced centrifugally under ultra-clean conditions by arcing to spinning electrodes of the desired powder composition.

Additional Applications

Other current developments include plasma heating as an alternative to natural gas-fired glass melters, incineration of hospital wastes, treatment of municipal incinerator fly ash, and the processing of soil contaminated by hazardous organics.

Future Developments

Widespread use of plasma heaters will occur for the simpler applications, i.e., heating and melting, such as the tundish and ladle heating, reactive metal melting, and reclaiming of metals from molten residues. As the complexity of the system increases, the applications will be more site-specific depending on local conditions for raw material availability, electrical costs, and environmental considerations.

Progress is being made in research and development of unique plasma synthesized products which have outstanding commercial promise.

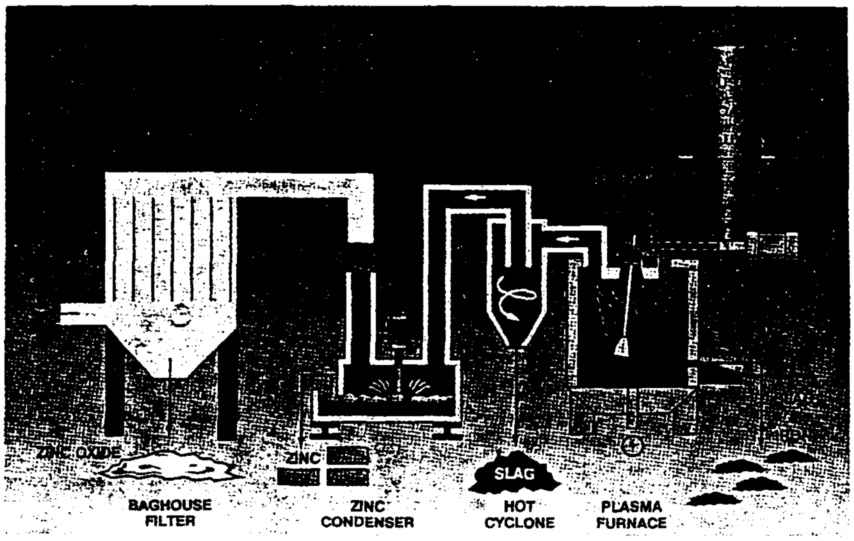

Figure 6.

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