Plasma Cupola Operations at General Motors Foundry

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ABSTRACT

General Motors' Powertrain plant, located in Defiance, Ohio has been operating the plasma cupola since June 1989 for the production of gray iron for making engine blocks and other automotive castings. This was the world's first commercial-scale plasma cupola ever built. The use of plasma heating technology allows GM plant to melt difficult raw materials in a cost effective manner and produce world-class automotive castings.

The technology development program that preceded GM installation began at Westinghouse in November of 1983 at the Plasma Center in Madison, Pennsylvania. A 2.5 tons per hour cupola pilot plant was built to investigate the use of plasma technology. Several test campaigns were conducted. Initial investigations studied the capability of the plasma cupola to handle and melt fine iron units like cast iron borings and steel turnings. Investigations were then extended to study the reduction of oxides of iron and silicon in order to produce metallic iron and silicon in-situ in the plasma cupola.

General Motors' Defiance foundry operates the plasma cupola to produce gray iron. The plasma cupola is used to melt loose cast iron borings produced at the engine plants. It is also used to melt regular scrap charge when the demand for hot metal is high. The plasma cupola and another conventional cupola are operated in a duplex manner. The foundry returns and sprue are directed to the conventional cupola which benefits from the "sweet charge" while the plasma cupola is operated essentially on scrap iron. This results in a cost effective foundry melting operation. The operating experience of the plasma cupola at General Motors' indicates that the plasma technology is suitable for the difficult foundry environment.

1. INTRODUCTION

The cupola is a vertical shaft furnace which has been conventionally used in the foundry industry for the remelting of scrap iron and steel. Unlike the traditional cupola, a plasma torch is fitted at the bottom of the shaft in a plasma-fired cupola (PFC). The plasma torch is a high temperature, high efficiency process heating device designed to operate with minimum maintenance in an industrial environment. The plasma torch converts the electrical energy into thermal energy of the gas thereby raising its temperature. In this application, the torch acts as a combustion air preheater operating at over 2500^{o}F thereby reducing the amount of coke and combustion air that is charged to the cupola. The resulting gas velocities through the cupola shaft are low enough to allow charging of smaller low cost materials such as loose borings and machining turnings.

In addition, thermal control of the plasma-fired cupola process is independent of the chemical control. The costly addition of alloy elements such as silicon, chromium and manganese is minimized and the higher temperatures in the lower sections establish reducing conditions in which silicon can be produced from sand and iron can be produced from the reduction of low cost iron oxides like mill scales waste material.

2. TECHNOLOGY DEVELOPMENT

2.1 Test Program

The plasma-fired cupola (PFC) technology was developed by Westinghouse Electric Corporation under Electric Power Research Institute (EPRI) sponsorship. In October 1983, a development program was formed with Westinghouse Electric Corporation, Pittsburgh; Electric Power Research Institute, Palo Alto; Modern Equipment Company, Port Washington and General Motors-Central Foundry Division, Saginaw. The development program later included participation from several major US foundries including General Motors, FORD, Intermet, Tyler Pipe, and others.

The program involved design, fabrication, installation and testing of a 2.5 ton per hour pilot-scale test cupola. For demonstration of the technology and intelligent extrapolation directly to production sized applications, the program participants decided not to build a laboratory type model but to construct a small but commercially sized operating cupola.

The test cupola was designed specifically to achieve the goals of the loose cast iron chip melting program. However, considering the unique capabilities of the plasma torch cupola, primarily its ability to create heat energy independent of either gas chemistry and mass flow rates in the shaft, the test cupola was designed with the flexibility to do much more.

The test cupola can operate with the major portion of the energy derived from coke combustion or alternatively from electrical power and also various intermediate combinations. The cupola was designed to achieve a non-oxidizing top gas characteristic to allow charging of nontraditional, very thin scrap at the charge door and minimize and possibly eliminate alloy oxidation losses. The ability to reduce silica to silicon was an important consideration. Sulfur behavior was considered, and an overriding general goal was a design that could very rapidly respond to a variety of upsets to achieve process control flexibility far beyond that obtainable with coke combustion only.

Extensive tests were conducted over a seven year period. The results [1] of this test program confirmed the flexibility of operation and the cost effectiveness of the PFC technology.

2.2 Pilot Plant

As shown in Figure 1, the pilot plant cupola is a combination water-cooled refractory-lined design with a shell diameter of 42 inches. It is lined to 30 inches diameter with refractory through the charge preheat zone and boshed down to a somewhat smaller inside diameter in the melting zone. The schematic diagram of the pilot plant cupola is shown in Figure 2.

The Westinghouse MARC 11 plasma torch is located in the tuyere zone of the cupola. This unit has the ability to supply up to 2000 kW of electric energy to the process. A relatively small amount of plasma air, typically 100 scfm, flows through the torch. Blast air in varying amounts can be supplied and mixed with the plasma torch flow in a special mixing chamber arrangement located between the torch and the cupola interior. Special refractory and water-cooling designs were incorporated at the torch-cupola connection.

This design allows the cupola to be operated as a super hot blast cupola with blast temperatures from ambient to 3000^{o}F or higher. The upper blast temperature range is limited only by the materials of construction and design of the torch-cupola junction.

Liquid iron and slag are continuously tapped and separated in a typical front slag spout arrangement. An open charge door is located high in the stack and, typically, top gas is burned in the upper stack and crossover duct before treatment in a wet scrubber. The cupola also incorporates a below charge gas take-off feature to facilitate recycling cupola gas.

An end dump skip type mechanical charger is used to load metallic charge materials, plus coke, alloys and fluxes, at the upper charge door. Charge materials are pre-batched and weighed in 55-gallon drums which are subsequently transported and loaded into the skip hoist by fork truck.

The loose cast iron chip feeder system consists of a storage bin with a vibrating feature connected to a calibrated screw conveyor for continuously feeding variable and controlled amounts of chips. Except for few initial heats, loose chips were fed directly through the charge door during most of the test program. The chip feeder system was used for introducing other granular materials to the system such as sand, finely divided coal or coke breeze and iron oxide in the form of fine mill scale.

A cupola gas recycle loop is incorporated in the system design. This loop facilitates extracting variable amounts of cupola top gas from the previously mentioned below-charge gas take-off, removing the larger particulate matter and reintroducing the gas to the melting process at the torch-cupola junction. The loop incorporates a mechanical cyclone and recycle fan plus necessary ducting and valves. The recycle loop flow can be turned on, turned off, or adjusted to achieve the goals of specific test melts.

The test cupola is completely instrumented and includes programmable Numa-Logic controller, gas analyses system, and a sophisticated Hewlett-Packard data acquisition system.

2.3 Results

The test results indicated that the plasma-fired cupola is capable of melting very thin charge material like loose cast iron borings up to 75% of the charge. This type of charge material can be fed directly through the cupola charge door. The melt rate can be increased by increasing the plasma torch power. A productivity increase as much as 60% is observed. The melt temperature can be controlled by varying the torch power level. The response time for such a control is in the order of 3-4 minutes.

The carbon monoxide levels in the top gas can be maintained, if required, at significantly higher levels in the PFC. This results in reducing atmospheres inside the PFC. This results in melt yields as high as 98.5% in the PFC. Also, due to very high temperature levels in the melt zone and higher carbon monoxide levels, silicon can be produced by the reduction of sand in the PFC. The silicon generation is more pronounced when sand is premixed with coke breeze and also when it is injected in front of the plasma torch. The ferro-silicon injection at the tuyere level also results in higher silicon recovery. Metal-to-coke ratios were varied between 8:1 to 70:1 during the test programs. Due to low wind rates, even at high metal-to-coke ratios, the cupola back pressure was observed to be in the moderate range. At high metal to coke ratios, most of the energy for melting iron is supplied by the plasma torch.

2.3.1 Plasma Effects

A first effect observed in the plasma cupola is the increase in productivity due to decoupling of the combustion process and total heat input to the cupola. The process energy of a normal operating cupola is derived mostly from the burning of coke which allows little control over gas chemistry in the cupola. On the other hand, the plasma-fired cupola can operate at various levels of electrical inputs whereby the energy can be derived relatively independent of coke combustion chemistry. The high energy output of the plasma torch can increase the production rate by as much as 50%.

A second effect observed in the plasma cupola is need for less air velocity and penetration. In the conventional cupola, combustion efficiency depends upon a certain air velocity from the tuyeres necessary to penetrate and provide air to coke surfaces into the center of the stack. The velocity necessary for good distribution results in a high velocity at the charge door and into the emission system. The emission equipment must be adequate to handle this high velocity effluent. On the other hand, in plasma cupola due to reduced coke usage and high energy plasma torch output, the total wind rate in the cupola is drastically reduced. This results in lower cost of air pollution control.

A third effect is less dependency on premium quality coke. In conventional cupola, for good combustion efficiency highest coke quality, strong and properly sized, is required to maintain the permeability and even air flow. In plasma cupola smaller size coke can be used with no drastic effect on melt rate or chemistry. During some pilot plant heats, anthracite coal was substituted in increasing proportions and reasonably normal melting was experienced using 100% anthracite coal.

A fourth significant effect in the plasma cupola is less oxidizing effect on charge material. In the normal cupola, the descending charge material is exposed to various levels of oxidizing and reducing atmospheres but with a net oxidizing effect. Silicon oxidation losses run 10-20% in an acid cupola, and 30-40% in a basic cupola. The slag normally contains iron oxide in the 1-10% range. With good combustion efficiency, the effluent gas runs 10-14% CO_2 and 14-10% CO. In the plasma cupola, depending on the nature of material fed through the tuyere, oxidation loss of silicon is in the range of -30% to 5%. Negative values of silicon oxidation loss indicates in-situ generation of silicon in the plasma cupola by feeding sand through the tuyere. Similarly, the FeO content of the slag is lower for the charge material melted. Effluent gas is far less oxidizing, ranging 1-7% CO_2 and 20-25% CO.

The less oxidizing nature and lower velocity of the effluent provides the plasma cupola with the ability to melt low cost charge material like borings, turnings and thin steel at the charge door without blowing out or excessive oxidation. Up to 75% loose borings have been introduced at the charging door. The prospect for direct melting of borings is most attractive to the automotive foundries.

A fifth significant effect is the reducing potential of the plasma cupola. Not only is the plasma cupola less oxidizing to oxidizable elements like silicon but has shown potential for reducing Si from sand. This feature is attractive to steel producers for melting of direct reduced iron (DRI) and for treatment of electric arc furnace (EAF) dust [2]. Due to strong reducing atmosphere in the melt zone of the plasma cupola, not only melting of metallic iron contained in DRI occurs but the unreduced iron oxide in DRI is also smelted. This increases the melt yield . Further, when EAF dust is fed through the tuyere of the plasma cupola, both zinc oxide and iron oxide is reduced. The iron is recovered as molten iron at the bottom of the cupola while the zinc vapors exit the top of the cupola and are collected in a concentrated form (>80% Zn) in the flue gas.

Following the trial heats in the plasma cupola, an EPRI funded study was conducted with the goal of defining plasma cupola economics for typical operating foundries [3]. The study showed attractive investment pay back period.

3. COMMERCIAL-SCALE PLASMA CUPOLA

Following the successful results of the development program, General Motors' Central Foundry Division decided to replace one of their existing production cupolas with the PFC technology at their plant in Defiance, Ohio. In March 1989, the first castings were made with metal from the plasma melter. The melter was dedicated on June 26, 1989 and released to production.

3.1 Plasma Melter

The GM melter is 13 feet in diameter. It has a throughput of up to 50 tons per hour when operated with charge of loose borings and close to 80 tons per hour with regular charge consisting of sprue and bundles. The melt rate for regular charge is currently limited by the capacity of the charging system. The gray iron is melted on top of the coke bed at about 2800^{o}F. The cupola shell is water cooled. Hot blast air is injected through the six tuyeres located at the bottom of the melter. A 1.5 MW Westinghouse MARC-11 plasma torch is mounted onto the end of each tuyere as shown in Figure 3.

General Motors uses plant compressed air at 100 psig as "plasma" source, it is run through a booster compressor to raise the pressure to 130 psig, it is then run through air dryers and filters before going to a distribution manifold where each torch is individually controlled and air is again filtered for each specific torch. The operating consumption is about 160 scfm per torch.

High quality de-ionized water is used for the cooling of the plasma torches, power supply components, and the power cables. The importance of maintaining high quality deionized water in the range of 200,000 to 400,000 ohms/cm is critical to maintaining long life expectancy of the water cooled components. The water system is not very large, it is a total of 1500 gallons in a semi-closed configuration with a nitrogen cover. It consists of torch pumps, power supply pumps , and recirculation pumps. General Motors uses plate heat exchangers, utilizing our large pond system water source as the means to remove heat from the deionized water.

3.2 Melter Operation

General Motors validated the physical and structural properties of the castings made from iron produced in the plasma melter. Sample castings were tested in engines on dynamometers. Results indicate that the iron produced by the plasma cupola meets or exceeds established quality standards.

General Motors is using the plasma melter to melt charges consisting of 50%-60% loose cast iron borings. During periods when demand for hot metal is high, GM runs the plasma melter with regular charge material and gets close to 80 tons per hour throughput. The melter is run on a three-shift operation. The plasma torches are operated in a fully automatic mode. The cupola operator starts all six torches by pressing one button on a master control panel. Also the power level is set by operating a single knob. Because of this feature, no engineer is required to operate the plasma systems. Figure 4 shows the picture of the plasma systems control panels.

3.3 Plasma Melter Charge

It consists of the following in General Motors plant for gray iron -

Material	Percent of Metal Charge	
	High-Throughput Campaign	Low-Throughput Campaign
Sprue	46.5%	26.5%
Bundles	10.0%	20.0%
Frag. Scrap	18.0%	-
Briquettes	23.0%	-
Steel Turnings	-	7.7%
Iron Borings	-	43.6%
Coke	9.3%	8.6%
Coal	1.3%	1.4%
Limestone	4.6%	5.3%
Plasma Power	4.5-7.0 MW	4.5-7.0 MW

Manganese and silicon are added downstream of the cupola. Iron chemistry control is watched more closely on a loose boring charge, just as a conventional cupola with a considerable amount of briquetted borings in it’s charge. General Motors tries to get “fresh borings” for the plasma charge of the PFC, being there is less oxide and more return of molten metal is realized.

Running a plasma cupola allows for additional savings that have to be calculated if you are running a multi-cupola operation. Specifically, a PFC can be a sprue generator rather than a sprue consumer. Thus, the sprue that would normally be required for that given cupola, can now be allocated to other cupolas and with a “sweeter” charge “the yield will be greater and operating costs are considerably less.

Heat recovery is much faster with the PFC. Although, General Motors never made it a practice to leave the PFC set longer than normal while spilled, we have had occasions that it did set much longer and still it re-tapped without problems.

3.4 Maintenance

The maintenance of the plasma systems is done by millwrights and electricians who underwent a short on-site training course. Normal maintenance consists of replacing the torch electrodes which is done every 750-1000 hours of operations.

Regarding the quality of the skilled trades people that maintain the plasma equipment, General Motors asked a few specific people if they had an interest in being in on the ground floor of this project. Both millwrights and electricians were good people, but not “specifically hand picked”. People are trained as they come and go, due to shift preference, bumps, etc., As it happens in most union shops.

General Motors worked with Westinghouse, making many trips to the plasma center and observing how the plasma torches were inspected and electrodes replaced. Westinghouse went to General Motors plant with a training program for the cupola operators , as well as the skilled tradesmen who would be covering the units on the repair shift as well as the other operating shifts. Basically, it was about 16 hours of training for each of the trades.

As General Motors began production operation of the plasma system, they started out with estimated hours of operation before tearing down a torch to inspect and check for wear of the electrodes. In a short time, General Motors found ways to improve on what we were doing to achieve lower maintenance costs and improve the life of he electrodes. General Motors started out at an expected minimum life of 240 hours on the downstream electrode (this is in operating hours), and 360 hours on the upstream electrode, with a projected life of 500 hours on the downstream and 750 hours on the upstream. With some very inexpensive adjustments in what they were doing, General Motors has extended the electrode lives to an average of 750 hours on downstream and 1200 hours on upstream, with 900 and 1500 operating hours respectively being achievable, though these are the exceptions.

General Motors has a procedure to track the hours of operation of each torch. At the end of the first 300 hours each torch is taken out of service and the electrodes are checked for wear. General Motors use a gage to check this, if the downstream is .40” or more, or the upstream is .25” or more, they are taken out of service. After the initial 300 hour inspection, then it is estimated when the next time for that specific torch is to be checked again. When torches are due to have the electrodes replaced, at that time General Motors also does a complete cleaning and replace o-rings, or any other minor components.

Shell wear has shown to be much less with the PFC than compared to a conventional cupola. The original cupola shell was installed in late 1988, with full production commencing in June of 1989. GM replaced the shell for the first time in 1996. Basically, due to the volumes run, historically GM has had to replace conventional cupola shells about every two (2) years.

Super heavy duty tuyeres are used with the PFC, they are compatible with the plasma torches, meaning there are not premature tuyere failures from the heat of the torches. The tuyere system is so designed so as that they are replaced from the outside, thus allowing production workers to do repairs on the well at the same time maintenance skilled-trades to be changing a tuyere if so required, saving on over-time costs.

4. CONCLUSIONS

Over five years of operating experience of the plasma melter at General Motors' Defiance plant, Ohio, indicates that plasma technology is economically suitable for iron melting. No major changes of traditional industry practices are required to operate plasma cupola systems. The plasma equipment can be operated and maintained by routine plant personnel.

The ability of the plasma cupola to smelt metal oxides is suitable for applications in the steel industry for melting of direct reduced iron (DRI) and also processing of residual wastes like electric arc furnace (EAF) dust and oily mill scale.

REFERENCES

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3. 3. S. F. Carter and F. T. Kaiser, "The Plasma-Fired Cupola-An Operator's Appraisal and Economic Projections, AFS Transaction Paper, 90th Casting Congress, May 11-15, 1986.

FIGURES

Figure 1 : Plasma Cupola Pilot Plant

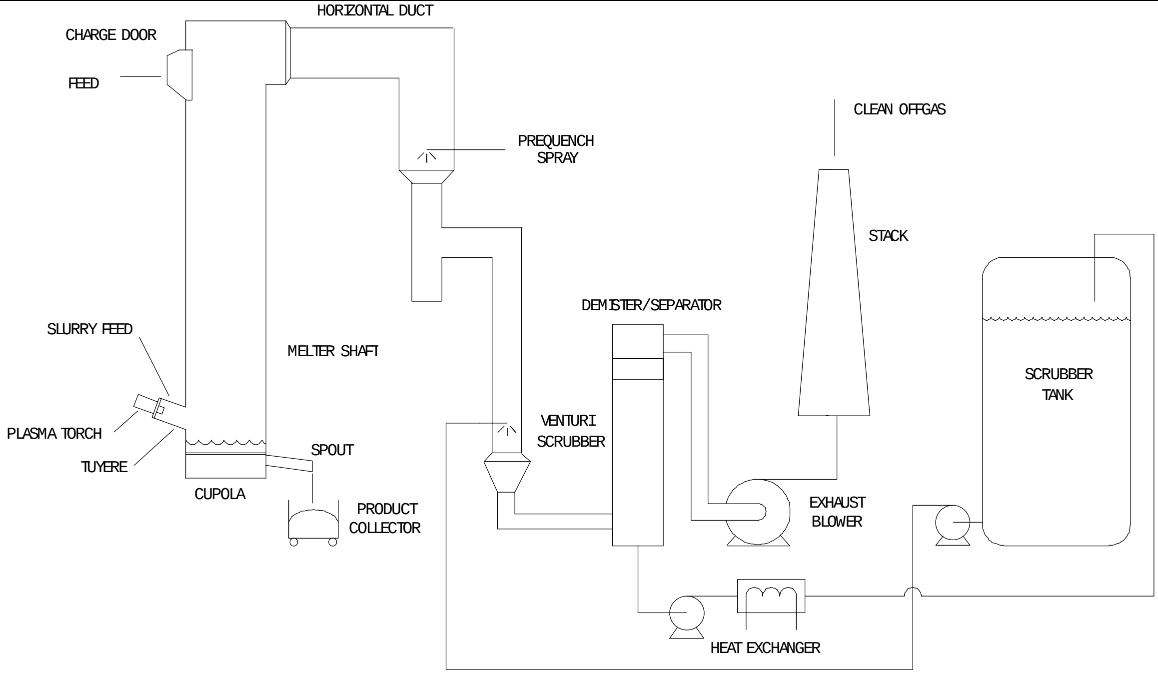

Figure 2: Plasma Cupola Pilot Plant Schematic

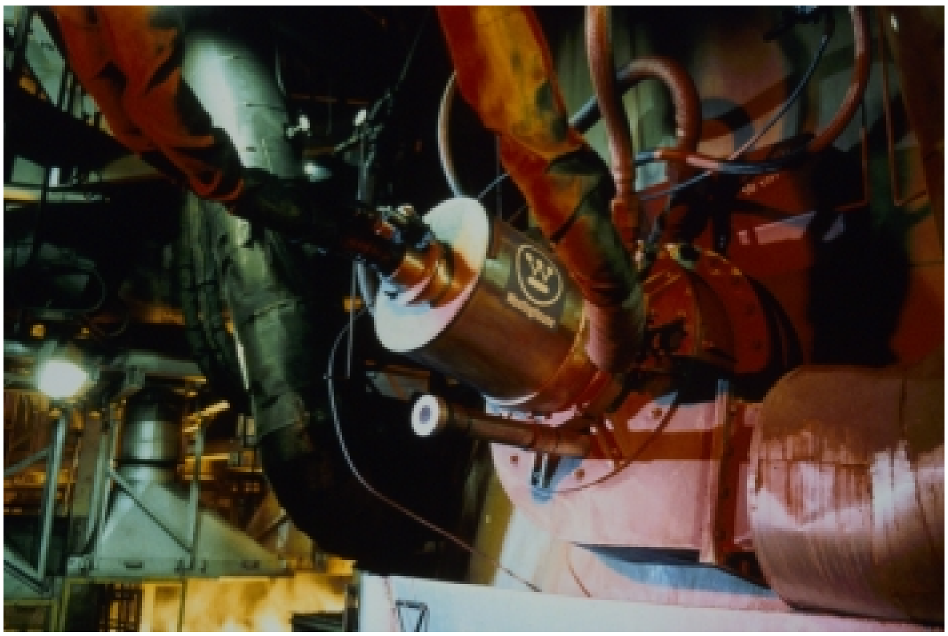

Figure 3: Plasma Tuyere at General Motors Cupola

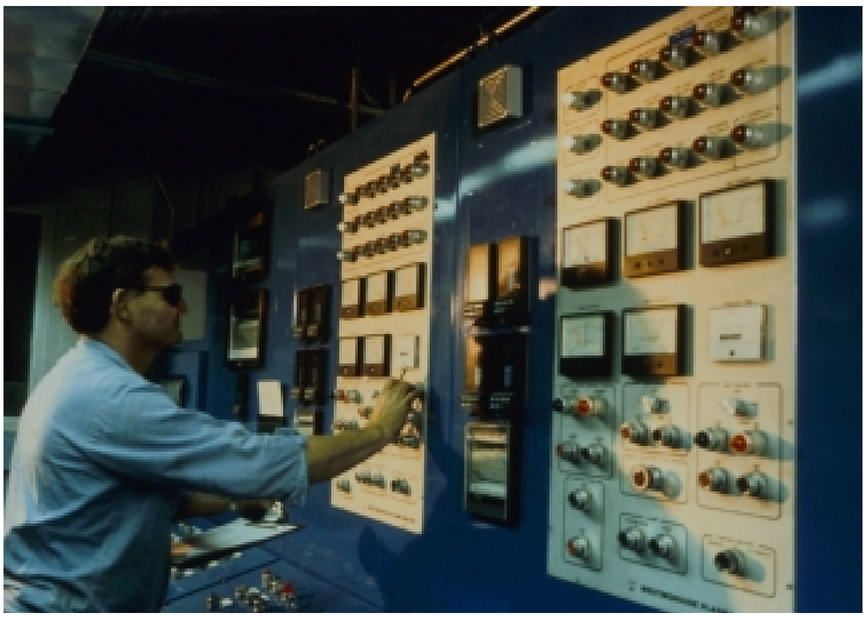

Figure 4 : Plasma Systems Controls at General Motors Cupola