Industrial Plasma Systems

INTRODUCTION

DEVELOPMENT OF WESTINGHOUSE PLASMA TORCHES
Westinghouse Plasma Corporation’s (WPC) plasma technology has been developed over 30 years with an estimated $100 million invested in research and development. The WPC technology was initially developed in collaboration with NASA for use in the Apollo space program to simulate space vehicle re-entry conditions of over 5,537°C (10,000°F). Alter NRG acquired WPC in 2007 and has further developed the plasma torches and plasma gasification process.

WHAT IS PLASMA?
Of the methods used to generate heat for an industrial process, most are typically limited to the combustion temperature of the associated fuel. WPC has overcome these limitations with the development of the plasma torch system. The plasma torch is an electric arc gas heater which can be utilized in high temperature industrial processes. As the process energy is provided by direct heat transfer from an electric arc, gases of widely varying chemical composition can be used.

Plasma torches have the unique capability of increasing the energy of the process gas by 2 to 10 times higher than that of conventional combustion equipment. As such, the plasma torch offers distinct advantages over traditional methods. These advantages include control of process variables, such as precise temperature regulation, process gas flexibility and increased process operating temperature not typically possible by conventional means.

PLASMA DEFINITION
Plasma is a high temperature, ionized, conductive gas created within the plasma torch. Plasma is created by the interaction of the gas with an electric arc. This interaction dissociates the gas into electrons and ions, enabling the gas to become both thermally and electrically conductive. The conductive property of the ionized gas in the arc region provides a way to transfer energy from the arc to the incoming process gas, and in turn, to the process or furnace. This state is called plasma and will exist in the immediate confines of the arc within the torch. As the gas exits the torch, it has recombined into its neutral (non-ionic) state although it still maintains its superheated properties.

WESTINGHOUSE PLASMA CORPORATION PLASMA TORCH ADVANTAGES
The WPC plasma torch provides flexibility and allows control over temperature, independent of fuel or oxygen throughput in the process. Other benefits of WPC plasma torches include:

- High reliability – over 500,000 hours in commercial operation
- Commercially proven in six plasma gasification facilities
- Availability in a wide range of power inputs from 80 to 2,400 kW
- Power input can be quickly adjusted to match process requirements
- Process temperature control
- Industrially-rugged design – proven in tough commercial environments such as steel mills, foundries and energy recovery from waste facilities
- Long electrode life
- High thermal efficiency
- Self-stabilized and non-transferred arc
- Simple design – no internal moving parts
- Torch gas flexibility (inert, reducing, oxidizing)
Plasma Torch Ratings

The plasma torch is a rugged, high temperature process heating device which is designed to operate with high efficiency and minimal maintenance in difficult environments. The following table lists the single unit plasma torches available from WPC. Exact ratings depend on the application.

The WPC MARC 3A or MARC 11 plasma torches operate over electrical ranges based on the configurations below.

<table>
<thead>
<tr>
<th>Torch Type</th>
<th>MARC 3A</th>
<th>MARC 11L</th>
<th>MARC 11H</th>
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</thead>
<tbody>
<tr>
<td>Rated Min Power (kW)</td>
<td>80</td>
<td>350</td>
<td>860</td>
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<tr>
<td>Rated Max Power (kW)</td>
<td>300</td>
<td>800</td>
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<td>Air Flow (scfm)</td>
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<td>Air Flow (kg/hr)</td>
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<td>Thermal Efficiency</td>
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<td>85%</td>
<td>85%</td>
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<tr>
<td>Maximum Operating Current</td>
<td>400 ADC</td>
<td>1000 ADC</td>
<td>2000 ADC</td>
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<tr>
<td>Maximum Operating Arc Voltage</td>
<td>860 VDC</td>
<td>950 VDC</td>
<td>1200 VDC</td>
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</table>

ARC IGNITER

A high frequency and high voltage arc igniter is coupled to the plasma torch to provide sufficient energy to break down the plasma torch gap between the upstream and downstream electrodes during torch ignition. The igniter is connected directly to the arc current path from the DC power supply to the plasma torch.

The MARC 3A and the MARC 11 use different arc igniters because of the difference in the maximum arc current for each torch. The arc igniter is designed for wall or floor mounting. The arc igniter enclosure is NEMA Type-12 construction and is dust-tight and drip-tight. From an installation perspective, the enclosure is located within 15 meters (50 feet) of the plasma torch.

MARC 3A PLASMA TORCH

WPC’s standard MARC 3A configuration operates in a range from 80kW to approximately 300kW. The current to the field coils in the MARC 3A is in series with the arc current. The MARC 3A does not feature independent control of the field coil current and arc current.

MARC 11 PLASMA TORCH

The MARC 11 torch power is controlled by changing either the arc current, field current or the process gas flow. Torch connections include quick disconnects for the air supply, cooling water and electrical connections to facilitate torch removal for inspection and maintenance. WPC has two standard MARC 11 configurations, a low power torch, the MARC 11L and a high power torch, MARC 11H. The low power MARC 11L plasma torch operates in the range from approximately 350 kW to approx. 800 kW.

The high power torch operates in the range from approximately 860 kW to 2400 kW. The maximum arc current of the MARC 11 plasma torch is 2000A. The MARC 11 torch uses two separate power supplies: one for the field coil and one for the arc. The arc current and the field coil current can be independently controlled.
Plasma Torch Performance Characteristics

WPC plasma torches operate over a wide performance range and with different types of gas. Power levels 5 kW to 2500 kW are attainable. The tables depict typical performance characteristics of a torch operated on air at arc currents of 800A and 1000A. With the arc current constant, the process gas flow is increased to provide a power level over 1 MW.

The arc current is continuously varied so that a series of these curves can be generated. As per the tables, a thermal efficiency of 90% is attainable. The efficiency represents the percentage of arc power which exits the torch and enters the process. Operational characteristics will vary with gas composition, and similar characteristics apply for the range of plasma torch ratings.

Control & Instrumentation

The plasma torch is controlled from a central panel (location determined by customer). The control panel functions are to control the operation of the plasma torch (torch on-off), control the arc current, display the arc voltage, arc current and arc power. The power supply contactor is also energized and de-energized from the control panel. Other functions include verification that the system is ready for operation (through interlocks and alarm lights) as well as the ability to interrupt power to the plasma torch if pre-selected conditions are not satisfied.

The control panel is interlocked to the torch cooling water, torch cooling water over temperature, torch gas flow, low arc voltage and low arc current. To energize the control panel it is necessary to use a safety key. The safety key is also required to access the power supply. The safety feature built into the system will minimized chances of damage to the plasma system and more importantly to the personnel operating the system.

Arc Power vs. Air Flow (MARC 11)

Efficiency vs. Air Flow (MARC 11)

The Control Room at Westinghouse Plasma Corporation’s Pilot Facility
**Plasma Subsystem Description**

**SYSTEM DESCRIPTION**

The plasma torch system is comprised of the following elements:

- Plasma torch
- Thyristor power supply
- Control and instrumentation system
- Process gas supply
- Cooling water system

Proper integration of these systems ensures optimal performance of the plasma torch system.

1. **The plasma torch** is the center of the plasma system with several subsystems needed for torch operation.

2. A **thyristor power supply** is utilized to provide DC power to the torch.

3. A **control system** is necessary to vary process parameters and to interlock the power supply, gas and, water systems.

4. The **process gas system** for the torch is supplied by a gas compressor or gas storage.

5. The electrodes in the torch are water cooled by a high pressure **water cooling system**.

### 1. PLASMA TORCH

A plasma torch consists of a closely spaced pair of tubular water-cooled electrodes. Inside each electrode is an electric arc discharge which is magnetically rotated at extremely high speeds. During operation, a process gas is injected into the torch header through one millimeter spacing between the electrodes.

Sparkover between the electrodes initiates the arc discharge when the power supply is energized. The arc is immediately dispersed to the interior of the electrode by the incoming process gas. The arc current interacts with a magnetic field established by a solenoid field coil located around both upstream and downstream electrodes and rotates the arc at approximately 1000 revolutions per second.

The gas/arc interaction produces the superheated process gas and leads to the high thermal efficiencies obtained for the plasma torch and the superheated gas exits at the downstream end of the torch. The downstream electrode end is designed to protrude the refractory lining of the furnace or process reactor.

The torch interfaces to the furnace or reactor by means of a mounting flange. The cooling water, process gas and power are connected to the torch at the upper (upstream) end of the external cover. All connections are designed for quick assembly and removal to minimize service effort.

Complete servicing for the torch consists of electrode and electrode seal replacement and a water pressure leak test. Trained service personnel can perform routine maintenance in 30-60 minutes.
2. **THYRISTOR POWER SUPPLY**

The plasma torch is connected to a thyristor power supply which provides a current controlled D.C. output. Depending on input voltage, the thyristor power supply typically includes a high voltage breaker or contactor for independent control and protection. A manually operated isolation switch is associated with the device for personnel protection during maintenance. A water cooled or air cooled transformer may also be used.

The secondary supply of the transformer is connected to the thyristor bridges. Several types of D.C. bridge configurations are available based on customer and site requirements. Bridges are supplied as either forced air or water cooled, based on space availability and site conditions. The current controlled D.C. output of the thyristor bridge is connected to a series iron-core inductor (smoothing reactor).

The inductor provides the required system impedance for arc stability. The plasma torch is connected to the load side of the inductor (primary switchgear can be provided as an option). The modular construction of the thyristor power supply reduces the user assembly and installation time as well as material and labor costs. Water cooling further reduces the package size and site preparation in addition to eliminating the need for an oil-filled transformer.

All major components are factory assembled and tested. The cabinet is typically supplied for indoor use with gasket doors and panels. The unit can also be equipped with heaters and a waterproofed cabinet for outdoor service.

3. **CONTROL AND INSTRUMENTATION SYSTEM**

Operation of plasma subsystems is controlled and interlocked to permit safe and simple operation of the overall plasma system. The control system consists of a console containing controls for the following: the cooling water flow, gas flow, field coil power, a display of various system parameters, and a series of interlocked relays. Under selected conditions, these relays allow certain primary sensors to both trip and lock out the protective device of the power supply.

The interlocking sensors insure predetermined values of field-coil current and cooling water flow, plasma torch electrode water flow, gas flow rate and any other system parameter selected. The control circuit contains appropriate alarms and trips to protect the integrity of the power supply and its components. All critical system parameters that are measured can also be equipped with an output for use with a data acquisition system or process controller.

A mechanically interlocked system is utilized to prevent improper sequence of equipment operation or access to electrical equipment while it is energized.

4. **PROCESS GAS SYSTEM**

Gas flow rates depend on gas composition and process requirements. Typical gas flow should be provided at a minimum torch inlet pressure of 90 psig (6 to 7 atmospheres), but may be varied to accommodate a range of process working pressures. The gas system includes a particle filter and flow regulation and measurement with low gas flow alarms and also with pressure and temperature indications. For any gas composition chosen, the dew point must be 10°C (20°F) below the minimum cooling water temperature.
5. WATER COOLING SYSTEM

To maintain the plasma torch components at a reasonable operating temperature and to reduce electrode wear, a cooling water system is required. High water pressure is required to provide high velocity water flow for increased heat transfer from the torch components to the cooling water. The system is a closed loop configuration with a pump and a heat exchanger. The heat exchanger should have a maximum capacity to dissipate the equivalent of 30 percent of the peak torch power with heat removed by the plant re-circulating water system. Inlet water temperatures can range up to 240°F (115°C).

Other components of the system include a surge tank, deionization system, make-up water connections, filter and strainer. Design of the system includes pressure gauges, appropriate valving, and flow switches. To protect the plasma torch in the event of a system failure, the water cooling system includes an emergency water source which automatically circulates at least 10 percent of the total cooling water through the plasma torch. This is accomplished with a city water supply and automatic valving.

As an alternative to the dedicated water cooling system described above, it is possible to use a plant closed loop water system. Depending on the capacity and water quality, this could be used as part of the primary plasma torch cooling water system or as part of a backup system in case of pump failure.

ELECTRODES

The primary part of every torch is the electrodes, which are used as electrical conductors. Each torch has an upstream and a downstream electrode. Once the electrodes are no longer usable, they need to be replaced (MARC 3A: 600 hours, MARC 11: 1,000 hours).
**FOUNDRY CUPOLAS**

Plasma systems are a solution for foundry problems of recycling cast-iron and steel machining chips. A plasma system applied to an existing cupola, allows direct charging of loose chips and borings and is a low cost source of iron units. Additional advantages of a plasma-fired cupola include:

- Reduced coke rates
- Reduced silicon loss
- Increased productivity
- Reduced air pollution controls
- Improved process control

**IRONMAKING**

Several technologies are presently used to produce molten iron from ore. The blast furnace has traditionally been the source of hot metal. To be economical a blast furnace complex must be built for very high production rates, with large capital investment, and operation dependent on coke as a reductant. Alternatively, the electric arc furnace using direct reduced iron has offered options to the blast furnace, but the pelletizing and reduction steps before melting increase the hot metal cost.

It has been demonstrated that iron ore concentrate can be injected into a plasma superheated reduction gas stream for rapid and complete reduction to molten iron. Coal can be used as the principal reducing agent, thus replacing coke as a reductant. If required, the resulting process off-gas can be used for pre-reducing the ore.

**PLASMA-FIRED BLAST FURNACE**

There are two methods for applying plasma to the operation of an ironmaking furnace:

In wind superheating, the hot blast (wind), exiting from the stoves is superheated in the hot blast main through mixing with high temperature plasma-heated air. This method increases wind temperature without shortening stove life or requiring the rebuilding of stoves to operate at the higher temperatures. The increased hot blast temperature can be used to decrease the coke consumption. Further reduction in coke consumption can be obtained by combining plasma energy addition with auxiliary fuel injection (e.g., natural gas, oil, tar, coal) at the tuyere zone. Coke is displaced by the auxiliary fuel added while the plasma energy permits independent control of the adiabatic flame temperature at the exit of the tuyere.

Plasma tuyere injection is an extension of the wind superheated case. By moving the plasma torch to the tuyere, the refractory lining is no longer a limiting factor for increased wind temperature. As in the wind superheated case, a hydrocarbon fuel will be injected to maintain the appropriate flame temperature at the exit of the tuyere.
The Westinghouse Plasma torches have been used to expand the operating parameters of metals applied in a high temperature application. High temperature plasma heated gases allow for testing at high thermal stress conditions. The temperature produced by the plasma torch system is approximately three times that recognized by conventional combustion methods. Results have consistently shown no contamination of tested materials.

The process utilized by Westinghouse involves an automated facility that can cycle the sample almost instantaneously – giving real time results. The results validate that the plasma torch assists in advancing the design of metals for high temperature applications. As an example of applications, the thermal barrier coating tests have been used to validate the integrity of ceramic coatings as part of turbine blades.

**Typical Plasma Applications**

The following applications are in varied stages of development (ranging from analytical studies, bench-scale laboratory tests, pilot plants, semi-works to commercial operations):

- Energy recovery from waste through plasma gasification
- Hazardous and medical waste destruction
- Combustion replacement
- Boiler ignition
- Foundry melters
- Ironmaking
- Plasma fired blast furnace
- Non ferrous metals processing
- Processing of metallurgical waste
- Plasma reformers
- Acetylene production
- Chemical processing
- R&D applications
- High temperature testing of ceramic and metallic materials
Westinghouse Plasma Corporation Capabilities

TECHNICAL CAPABILITIES

Extensive background and experience in analytical, experimental, and commercial aspects of high temperature chemical and material heating processes have made WPC a leader in the development of plasma technology.

Plasma can be applied to many industrial processes. To help predict process effectiveness, computer models have been developed for particle heating, heating with mass transfer, and heating with chemical reaction and mass transfer. By applying the results of the computer analysis, the design of a plasma gasification process can be translated into commercial reactors. Additionally, with engineering expertise in heat transfer analysis, system design, system integration, experimental testing, auxiliary systems design and electrical, mechanical and chemical analysis, WPC has the capability to develop prototype designs in numerous process areas.

QUALITY GUARANTEED

- WPC Torches are manufactured in the USA and can be delivered anywhere in the world
- WPC personnel have over 75 years of combined experience to install, troubleshoot and support the plasma torch systems
- WPC’s continuous improvement process works to reduce capital and operating costs while improving power output ranges
- WPC provides aftermarket continuous client support and warranties for the torch systems
- WPC predictive modeling using VMG Simulation software creates preliminary designs for balance of plant configurations

WESTINGHOUSE PLASMA CORPORATION PILOT FACILITY

WPC has a 48 tonne per day pilot facility in Madison, Pennsylvania, USA. Over 100 different varieties of feedstocks have been tested to provide baseline information for research and customers. Given the high operating temperature of the plasma torches the facility has the capability to test a wide range of feedstocks.

The facility is equipped with state of the art equipment including real-time gas composition monitoring to identify the composition and energy value of the syngas.
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<tr>
<th>Date</th>
<th>Customer Application</th>
<th>Plasma Torch Systems</th>
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<tr>
<td>2010</td>
<td>Undisclosed Client – Metals research</td>
<td>MARC 11H</td>
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<tr>
<td>2010</td>
<td>SMS Infrastructure, Ltd. Commercial Vitrification of Common Hazardous Waste</td>
<td>MARC 3A</td>
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<td>2009</td>
<td>SMS Infrastructure, Ltd. Commercial Vitrification of Common Hazardous Waste</td>
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<td>2005</td>
<td>Georgia Institute of Technology Laboratory Application</td>
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<td>2002</td>
<td>Hitachi Metals Ltd. Commercial Gasification of MSW &amp; Waste Water Sludge</td>
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<td>2001</td>
<td>Hitachi Metals Ltd. Waste to Energy Facility Gasification of Auto Shredder Residue &amp; Refuse Derived Fuel</td>
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<td>1995</td>
<td>Geneva Steel Corporation Commercial Production of Molten Iron for Steel Making</td>
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<td>DuPont Corporation Materials Synthesis Development</td>
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<td>Ishikawajima-Harima Heavy Industries Co. (IHI) Commercial Vitrification of MSW Incinerator Ash</td>
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<td>China Steel Co. Research Lab for Metals Production</td>
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<td>Consarc Corp. Research Center for Refining of Refractory Metals</td>
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<td>Eldorado Resources Ltd. Extraction of Uranium from Magnesium Fluoride Research Center</td>
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<td>Pyrolysis Systems Inc. Mobile Trailer for Liquid Toxic Waste Destruction</td>
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<td>Intermountain Power Co. Commercial Ignition of a Pulverized Coal Boiler</td>
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<td>Owens-Corning Fiberglass Research Lab.</td>
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<td>Studsvik Energiteknik Thermal Simulation of a Nuclear Reactor Core Meltdown</td>
<td>MARC 11</td>
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<td>Pickands -Mather Co. Metal Project Development of Plasma Iron Reduction and Steelmaking</td>
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<td>SKF Steel Co. Commercial Sponge Iron Production</td>
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<td>Westinghouse Research Jet Propulsion Lab. NASA Production of Solar Grade Silicon</td>
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<td>Westinghouse Research Arc Heater Project</td>
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<td>International Minerals &amp; Chemicals Corp. Phosphate Deffluorination Process</td>
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