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AC Plasma Arc System for Pyrolysis of Medical Waste and POPs

Paper #77

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ABSTRACT

Plasma technology is an environmentally friendly method to destruct hazardous wastes. Using the arc discharge with the plasma gas like hydrogen, the temperature can attain 7000°C in arc zone and above 1200~1500°C in reaction zone. Due to such high temperature, the chemical bonds of organic compounds are broken up, and then the process achieves high destruction and removal efficiency (DRE) and avoids the emission of NO_x, CO and dioxins. As the additives such as CaO and SiO_2 are mixed with the wastes, solid by-product of the process is the vitrified slag with some heavy metals in it.

In this paper, a pilot-scale AC plasma arc system was designed and installed in the Wastes Treatment Technology lab, Institute of Mechanics, Chinese Academy of Sciences (CAS-IMECH) to investigate the capacity of plasma arc technology for medical waste treatment. The plasma system, with the capacity of 5 ton/day, includes a feed-in subsystem, a 250 kW plasma arc furnace, a monitoring/controlling subsystem, an plasma gas supply subsystem, a water-cooling subsystem, and an off-gas treatment subsystem that consists of a secondary combustion chamber, a fast off-gas cooling heat exchanger, an active carbon-fiber adsorbing box, a wet acid-gas scrubber and an off-gas reheater. The performance characteristics of this plasma arc system has been tested and evaluated. Moreover, cooperating with Mega-Green Environmental Science and Technology Co., Ltd, CAS-IMECH is developing a demo plant for the treatment of Persistent Organic Pollutants (POPs), medical waste and other toxic organic wastes in Xianyang, Shaanxi Province, China.

INTRODUCTION

With the industrial development, environmental pollution has become a serious problem in China. The main hazardous pollutants are from hospital, chemical factory, etc.. Chinese government pays deep attention to environmental protection and the legislations on disposal scheme and emission control become much stricter than before.

Compared with conventional incineration, plasma technology is a relatively efficient way to destruct hazardous wastes. Via the arc discharge, plasma arc technology is able to raise pyrolysis temperature as high as 1500°C to 2000°C, which leads to the effective cracking of the chemical bonds of organic materials. In reductive atmosphere, such an approach can completely inhibit the formations of oxidized pollutants such as NO_x, SO_x and CO. It has been reported that the plasma technology only converts wastes into a slight amount of pyrolysis gases, a number of carbon soot and the vitrified slag, and these products are easy for further treatment or to be recycled. The plasma technology achieves great destruction and removal efficiency (DRE) for hazardous waste treatment, smaller reactor and

auxiliary equipment; it can be relatively fast turned on or shut down; the stable operation can be easily achieved; competitive processing cost for hazardous wastes.

AC plasma arc metallurgy technology (3-phase, 50Hz) was developed in CAS-IMECH from later 1980's to 1995. After 1995, it was applied to destruct hospital waste, chemical waste including polychlorinated biphenyls (PCBs), chemical agents, waste polymers, electronic circuit boards, pulp mill slurry and hazardous waste with arsenic and sulfur constituents. [1-3] In 2005, a 30 kW DC plasma arc reactor was designed to treat hazardous wastes in the lab, which was used to study the formation mechanism of the vitrified slag, the transfer mechanism of hazardous elements and the formation mechanism of gaseous pollutants. Various hazardous wastes have been destroyed and vitrified with this reactor [4]. Furthermore, it succeeded in building up a plasma treatment system for solid hazardous chemical wastes in Zhonghao Chenguang Research Institute of Chemical Industry in Sichuan Province, China, in 2006, which is the first full-scale plasma treatment system for solid chemical hazardous wastes in China. Co-operated with a Shenzhen-based company, Mega-Green Environmental Science and Technology Co. Ltd. CAS-IMECH set up a joint venture, named Casimech-Green Plasma Research Co. Ltd. And at present, the joint venture is engaged to build up a demo plant in Xianyang, Shaanxi Province to treat POPs, medical waste and hazardous wastes by its own technology, and to form the productivity for plasma waste treatment facility.

AC PLASMA ARC SYSTEM

An integrated laboratory system for the treatment of medical waste by AC plasma arc pyrolysis was recently built up (Figure 1). The system introduces H_2 to form reductive atmosphere, consumes less plasma gas and produces low volume off-gas of 200~300 Nm^3/hr. This system, with the capacity of 5 ton/day, is a pilot-scale demonstration unit and can be used to destruct gases, liquids and solid wastes. Since using graphite as furnace liner and electrodes, the system can be used to treat strong-corrosive CFCs wastes containing fluorine. It consists of a

Figure 1: Laboratory Plasma System for Medical Waste Treatment

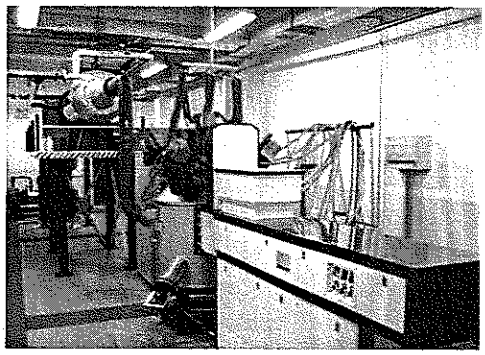
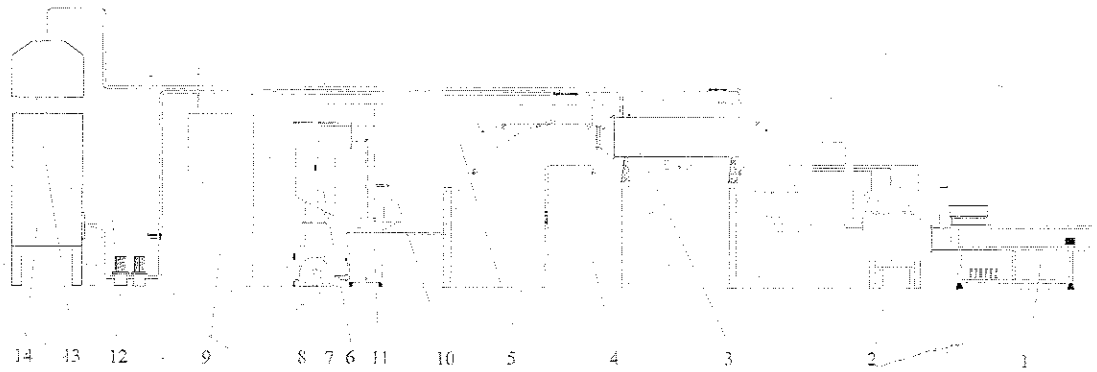


Figure 2: Laboratory Plasma System for Medical Waste Treatment



1.Feed-in subsystem 2. Plasma arc furnace 3. Heat exchanger 4. Air preheater 5. Active carbon-fiber adsorber 6. Scrubber 7. Off-gas reheater 8. I.D. fan 9. Secondary combustion chamber 10. Alkali solution 11. Dechlorination water tank 12.Water pump 13. Cooling tower 14.Water tank

simplified feed-in subsystem, a plasma arc pyrolysis subsystem as the core equipment, an off-gas treatment subsystem and a water-cooling subsystem, etc. The plasma arc pyrolysis subsystem consists of a plasma arc furnace, a power supply subsystem, a monitoring/controlling subsystem and a plasma gas supply subsystem. The subsystem for off-gas treatment includes a fast cooling heat exchanger, an air preheater, a carbon-fiber adsorber, a wet scrubber for dechlorination, an off-gas reheater, an induced fan (I.D. fan), a secondary combustion chamber, etc. In addition, the water-cooling subsystem contains a cooling tower, a water tank, a heat exchanger and other accessories. Figure 2 illustrates a brief description of the treatment process.

The system before the combustor is designed as sealed and explosion-resistant system. To prevent the gases from leaking out of the system, the entire system maintains slight negative pressure with ten or more mmH_2O less than the atmosphere pressure. The amount of air infiltration into the process units is limited to a safe bound by the seal system, which is much lower than the explosion limit of Hydrogen (approximately 4% to 75.6%). In addition, a great number of former experiments adequately indicated that these equipments can be operated in a safe and stable process.

Feed-in Subsystem

For the pilot-scale system, the feed-in subsystem is a typical double-ram charging system assembly designed to minimize the quantity of air infiltration into the furnace when charging. It consists of a hopper used for feeding of solid wastes, two hydraulic ram actuators to drive the charging ram face which pushes the wastes into the furnace, a hydraulic fire door actuator which drives the guillotine fire door, and a control panel. The furnace charging door is not opened until the hopper is sealed by one of the two rams, preventing air infiltration from the hopper. Furthermore, the negative atmosphere in the plasma furnace ensures that no plasma gas infiltrate into the feeder when the charging door is open. The full-scale integrated medical waste treatment system also involves an isolated space with an additives storage tank, a shredder, a conveyor, an ultraviolet device, an additives screw feeder and a seal system.

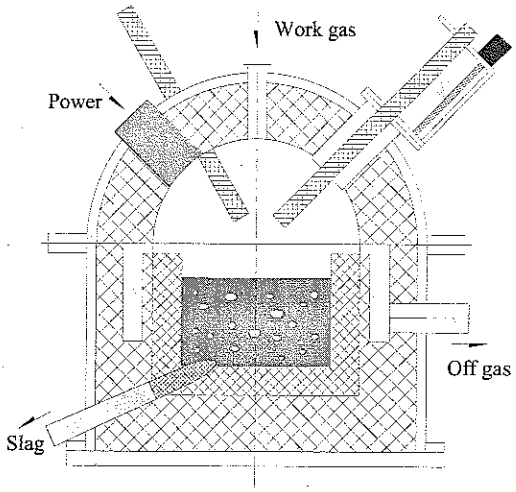
AC Plasma Arc Furnace

Compared with DC plasma torch technology, the plasma arc technology has advantages as follows: (1) The efficiency is more than 80% without energy waste for converting from AC to DC. Using torch technology, the water-cooling copper is used as anode, thus the cooling water will take away much energy from the furnace to prevent the anode from ablation. AC plasma arc technology uses graphite as electrode which has a very high melting point and electrode ablation is not serious, so it is not necessary to use water-cooling and the energy efficiency is much higher than plasma torch technology; (2) Hydrogen as the plasma gas, provides a reductive atmosphere in the furnace, inside furnace is in pyrolyzing condition (almost no oxygen consumption), big molecules can be cracked down into H_2、CH_4、CO and other small molecular combustible gas, so there are no NO_x formation in the off-gas and no suitable conditions for the reconstruction of dioxins, furans or other hazardous organic compounds; (3) The metal oxides are deoxidized into heavy metals which will be melted, concentrated and discharged. As the additives, such as CaO and SiO_2, are mixed with the melted wastes, solid by-product of the process is the vitrified slag with some heavy metals in it; (4) It is a mobile-type facility and can be operated in a batch process, because of the fast pre-heating process, the startup or shut down time is only several minutes.

The furnace shown in Figure 3 is based on 3-phase AC 50Hz plasma arc metallurgy technology. The

operating voltage is 70~80V AC with the power capacity of 250 kW. The plasma arc furnace includes an AC plasma arc generator, a reactor tank, an set of electrode driving machine, a feed-in system, a cooling system and a taphole system etc., the temperatures can attain above 7000°C in arc zone, 1200~1500°C in reaction zone and 900~1100°C at off-gas port, the output of the slag forms vitreous slag. Three graphite electrodes are moveably fixed by three sets of driving machines, and there is a cooling-water channel inside the jacket to cool the driving machines to about 300~400 °C. The electrode driving machine uses drift structure to fix the electrodes and controls the axial shift direction of the electrodes by two flanges fixed in the upper and lower sides of the driving machines. When the electrode ablation occurs, it has the capacity of fast-locking to ensure the continuous moving of the electrodes and the position of the electrodes in the furnace can be shown in the monitoring panel at the same time. The power supply is contacted with the electrodes with the electric current of 1800A. The furnace is insulated against the electrodes with asbestos layer and equipped with high temperature sealing to inhibit plasma gas from leaking.

Figure 3: Schematic Structure of the Plasma Furnace



Off-gas Treatment Subsystem

Fast Cooling Heat Exchanger

The off-gas generated by the plasma arc reactor is about 200~300 Nm^3/hr, and a fast cooling heat exchanger where the off-gas resident time is less than 1 second is installed directly after the reactor. The gas and cooling water are non-contact in the exchanger, the off-gas flow though several array pipes arranged inside the exchanger; the cooling water flow though the external pipelines and then will be returned to the water tank and recycled. In order to avoid scale depositing because of high water temperature, the temperature of water inside the tank is controlled at 60°C, rather than installing water soften equipment. If the temperature above 60°C, a part of recycling water will be discharged and fresh water is injected into the tank. In this way, not only does it save a great deal of water which is very scarce in China, but also reduce both investment and operating cost of water treatment facility. The exchanger with heat transfer area of 28 m^2 and the flue cross-section of 0.11 m^2, can cool the gas temperature from 1200°C to approximately 600°C in less than 1 second. To avoid acid corrosion, Inconel 625 alloy is chosen as the pipe material of the exchanger for demo plant, but for the lab system the carbon steel is employed.

Air Preheater

The off-gas from the fast cooling heat exchanger will be cooled further by the air preheater (heat fresh air to 150°C, while the temperature of the off-gas reduces to around 500°C). It consists of two concentric cylinders. The cooling-air goes through the outer one, and the off-gas goes through the inner one and then enters into the active carbon-fiber adsorber. The hot air can be led into the off-gas reheater and incinerator, where it can improve energy utilization efficiency as secondary air.

Active Carbon-fiber Adsorber

Dioxins, furans, heavy metals, soot, etc. in the off-gas are adsorbed by an adsorbing box filled with an active carbon-fiber as filtration medium, which has the advantages of large adsorbing area, extensive adsorbing capacity and high efficiency. In order to reduce the investment of material storage or injector, the active carbon-fiber is filled into a drawer, so it is convenient for the carbon-fiber to be filled and replaced. The replacing carbon-fiber are taken out from the drawer and loaded in a plastic bag and then put into an incinerator. The fabric filter is not fixed in the system, because of small amount of off-gas taking little particles in it. However, a fabric baghouse is built up in this position in order to catch more fine particles in industrial system.

Wet Acid-gas Scrubber and Off-gas Reheater

The off-gas after removal of particles is turned into a wet acid-gas scrubber, where the acid gas (such as HCl and SO_2) in the off-gas is removed by alkaline solutions, such as limewater or NaOH solution. The acid-gas scrubber uses stainless steel spiral nozzles to ensure that the acid gases are completely neutralized by alkaline solutions, which avoid the influence of nozzle choke on de-acidification efficiency. Through detecting the *pH* value of recycling water, the injection rate of alkaline solution can be controlled by a central control system. The outlet off-gas can be reduced to around 130°C and then turned into the reheater where the off-gas is heated to above 150°C by the hot air from air preheater so as to avoid dewing in the pipes, and then discharged to a combustor.

Secondary Combustion Chamber

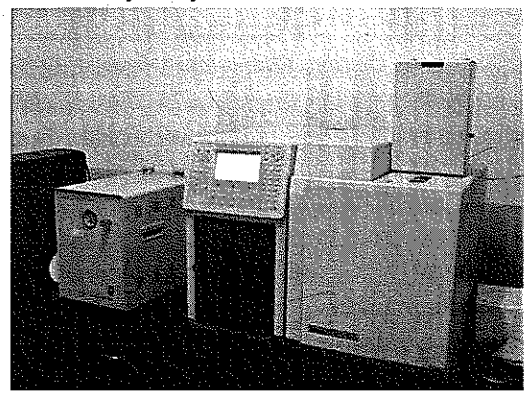
Different from other plasma treatment system, the secondary combustion chamber is set up at the end of the system. In the presence of HCl and fly ash, incomplete combustion and asymmetric catalysis reaction may form different kinds of organic precursors such as chlorophenol, which will synthesize polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/Fs). In this system, catalyzed materials fly ash and HCl will be removed by adsorbing box and acid-gas scrubber at first, thus the off-gas into the secondary combustion chamber consists of pure combustible gases, which have no influence on the PCDD/Fs regeneration, so that PCDD/Fs formation should be minimized completely. Since there is no need for hazardous wastes destruction, its temperature can be lower than conventional secondary chamber. The amount of generated NOx is much lower than conventional incineration.

3-T principle is applied in the secondary combustion chamber design, the gas residence time is about 2s [5]; the incineration temperature reaches 850~1100°C; the mixed combustible gas is in turbulent combustion. In this case, the off-gas is incinerated completely and the synthesis of PCDD/Fs is inhibited efficiently.

Off-gas Measurement Subsystem

At present, a gas chromatography (Varian CP-3800) analysis system (shown in Figure 4) has been set up in the lab. The components and content of the off-gas from the plasma pyrolysis system or other incinerators can be accurately analyzed on this analysis platform that is regarded as the basic emission test technology. The off-gas is filled in the sampling bag, and

Figure 4: Gas Chromatography (VarianCP-3800) Analysis System



then injected into capillary injector (Type 1177). Equipped with capillary injectors, the platform can adopt different kinds of optimized electronic flow control modes and capture reliable data by manual pneumatic control or electronic flow control. The samples are separated by three columns effectively and then flow into three different detectors. Of the three matched quantitative detectors, Thermal Conductivity Detector (TCD) can detect organic, inorganic, non-destructive molecules and the detection limit is 0.2 ppm; Flame Ionization Detector (FID) can detect combustible organic molecules and the detection limit is 10 pg(pico gram)/sec; Pulsed Flame Photometric Detector (PFPD) is generally used to detect P、S、N elements, the detection limit is respectively P: 0.1pg/sec、S: 1 pg/sec、N: 20 pg/sec. Fast heat-up (100°C/min) and rapid cool-down column oven (400°C to 50°C in 4.5 min) allow for faster cycle times and increase the productivity. Industrially standard Ethernet connection confirms the effective net environment and it is fully functional as a standalone GC or controlled through the Varian Star Workstation or the Galaxie Chromatography Data System.[6]

Operation Performance and Industrial Application

The plasma furnace in CAS-IMECH completes a plasma arc pyrolysis system with reductive atmosphere. The technology is based on several Chinese patents such as 3-phase AC plasma metallurgy furnace, plasma arc technology, etc., it adopts Hydrogen or Argon as plasma gas to get reductive atmosphere, its feasibility is confirmed by using the pyrolysis treatment experiments of various wastes such as chemical warfare agents, chemical wastes, medical wastes and electronic wastes. Several tests and analyses have been performed on the compositions of produced slag by XRF (X-Ray Fluorescence), SEM (Scanning Electron Microscope), etc., the details have been discussed in the former references and show that the hazardous elements such as As, Cd, Cr, Cu, etc. have been collected and vitrified in the produced slag and the amount of fly ash in off-gas is very low. The chemical agents contain arsenic were destructed in the 3-phase plasma arc furnace in the lab, the arsenic content in the off-gas, vitrified slag, waste water and soot are 0.052 mg/l, 3.0%, 10.44 mg/l, and 5.1% respectively, which will be disposed as the pollutant matters.[2] In addition, the chemical wastes which contain 15% PCBs were treated in the furnace, the contents of two different wastes after disposal were analyzed by National Environmental Analysis Center of China. It indicated that destruction and removal efficiency (DRE) of chemical waste is more than 99.999%, and the solid residues contain PCBs in the range of 1.28 mg/kg to 12.9 mg/kg, which is far below the National emission limit value for hazardous wastes.[3] The test results reveal that plasma technology is an environmentally friendly technology to destruct hazardous wastes.

Except the lab system, the first set of domestic-made industry-scale treatment system of hazardous solid waste from chemical plant (Containing 15% PCBs) with the capacity of 3 ton/day, was built up at Zhonghao Chenguang Institute of Chemical Industry, Sichuan Province, China by CAS-IMECH in later 2006 (Figure 5).

Figure 5: The First Industry-scale Plasma Chemical Waste Treatment System in

The differences between this system and the lab system are the former treatment system is applied to destruct hazardous wastes such as chemical wastes, solid POPs, etc., consisting of a raw material storage, a solid particle crusher, an additives storage tank, an additives feed-in monitor, a mixture machine of raw material and

additives, a feed-in monitor, a PC control system, etc. The DC power supply of plasma generator is 150 kW, and Argon is employed as the reaction gas. The features of the off-gas subsystem are that in order to recover HCl, the natural gas-fueled secondary combustion chamber is directly set after the plasma pyrolysis furnace, the carbon and combustible gases are burnt out by natural gas, then hydrochloric acid is recycled by three-stage acid gas scrubber/ recycling tower and then recovered. Through the detection of the environmental protection workshop in the plant, the output amount of off-gases meets environmental standard, and PCDD/Fs and PCBs are not detected. Fig. 6 is the operating parameter of the DC furnace in constant feed-in process. It is shown that the operating power of the furnace is in the range from 54kW to 63kW. In the operating process, it is necessary to change the position of the electrode to stabilize the operating voltage of the furnace. The major composition of the wastes is shown in Table 1. The wastes are fed into the furnace with 0.9 kg/min and the pressure in the furnace maintains -212 to -350 Pa.

Fig. 6 Operating parameter of the DC furnace in constant feed-in process

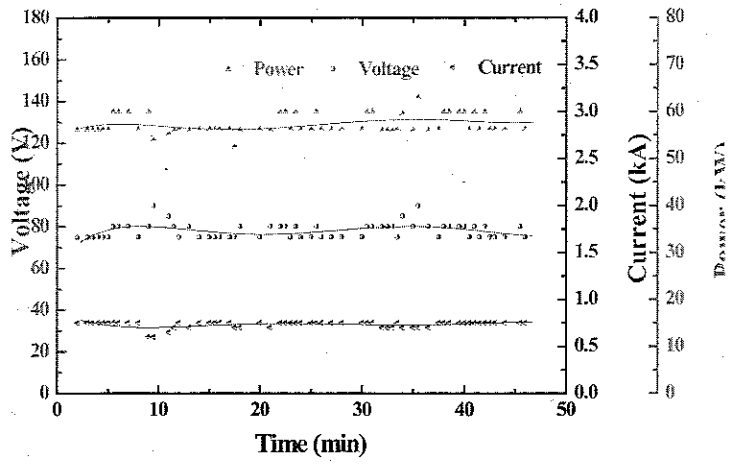


Table 1 The major composition of the wastes

Composition	Wt.%
Diphenyl dichlorosilicane	~40%
Triphenyl chlorosilicane	~40%
PCBs	~20%
o-Terphenyl	Below 1%
m-Terphenyl	Below 1%

Recently, a joint venture, Casimech-Green Plasma Research Co., Ltd. (Shenzhen, China), set up by CAS-IMECH and Mega-Green Environmental Science and Technology Co., Ltd., has started to build a plasma-arc pyrolysis demo plant in Liquan County, Xianyang City, Shaanxi Province with the capacity of 5 ton/day, which is used to destruct hazardous wastes such as POPs, medical wastes, etc. The integrated plant consists of a heat recovery system to produce steam to disinfect the plastic wastes, which can be recycled after disinfection. To simplify the operation, the off-gas combustion chamber is fixed directly after the plasma reactor and before the boiler, thus, the combustible gas will be burnt out, and there is no explosion risk.

CONCLUSIONS

The system in the lab, with the capacity of 3 to 5 ton/day, is a pilot-scale demo unit and can be used to destruct gases, liquids and solid wastes. In addition to medical wastes, the system can be used to treat strong-corrosive CFCs wastes containing fluorine due to graphite as furnace liner and electrodes Hydrogen as working gas provides a stable reductive atmosphere in the AC plasma arc furnace. The

heavy metals are stabilized and immobilized in the vitrified slag, and the emission is lower and much less harmful than incineration. HCl, fly ash containing heavy metals, H_2, combustible gas, etc. are disposed of by the integrated off-gas treatment subsystem, and the pollutant emissions of the system achieve almost zero. The installation and research of the complete plasma arc pyrolysis system in the lab construct a stable research foundation for the further industrial application, and the former study on hazardous waste destruction shows it is an efficient and environmentally friendly technology.

ACKNOWLEDGMENTS

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KEYWORDS

AC plasma arc technology; Pyrolysis process; Medical wastes; Off-gas treatment