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Thermal Plasma Process for Hazardous Waste Treatment

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***Abstract* - A thermal plasma is an electrically conductive gas in which an important fraction of the atoms are ionizedand capable of generating temperatures up to 10000'C near its column with appropriate high tech. The energy generated by plasma arcs has been recently applied to hazardous waste control. The technology involves subjecting hazardous material to high temperatures with the purpose of immobilizing nonvolatile chemical species into a non-leachable matrix. Plasma arc vitrification processing is well known for special waste disposal requirements. In addition to its ability to sustain high temperatures, other attractive plasma technology features include its flexibility to operate in either an oxidizing or reducing environment, resultant waste volume reduction, low gas throughput, and flexibility to treat a large variety of waste types. The author has been actively working in the research and developmental efforts undertaken to establish plasma technology as an efficient, economical, and safe hazardous waste destruction tool. This paper outlines the high tech thermal plasma processes and tries to establish the technology as a uniquely efficienttool in hazardous waste destruction, such as hospital wastes, pyrotechnic smoke assemblies, thermal batteries, and contaminated soil which may be met through utilization of Military Tools.Results show that thermal plasma processes are effective in hazardous waste treatment and environmental remediation.**

Key Words:Thermal plasma process, plasma torch, hazardous waste, slag.

I. INTRODUCTION

Hazardous materials such as found in hospital wastes, military wastes, and asbestos from demolished buildings have always posed a great danger to health and environment. Accumulating stockpiles, high storage costs, and the potential for long-term liability are illustrative examples defining the magnitude of the hazardous waste disposal issue facing both governmental and private organizations. In Nigeria, development of new cities such as Abuja has given rise to the need to demolish illegal structures which are not within the master plan. Hospitals and Military organizations churn out hazardous wastes that are difficult to control by conventional methods of waste disposal such as land filling and incineration without hurting the environment. Landfill releases methane which is 21 times more dangerous as a greenhouse gas than carbon dioxide, [1].

One of the technical challenges in disposing of hazardous wastes is the wide variability in waste media. Hazardous waste may either be solid or liquid waste streams or may contain such environmental hazards as asbestos, heavy metals, or organics or any combination of the mentioned waste components. For instance, in 1994 alone, the U.S. Army generated 640 tons of multi-phase toxic containerized liquids, 523 tons of bulk toxic pumpable liquids, 530 tonsof multi-phase containerized solvents, and 128 tons of pumpable solvents. Current treatment of these liquid containing waste streams cost approximately $1250 to $2700 per ton [19],[20].The U.S. Environmental Protection Agency (EPA) has identified eight Toxicity Characteristic Leaching Procedure (TCLP) metals which represent environmental hazards and whose disposalare strictly regulated, [2],[3]. Fig. 1 summarizes these metals prevalence in various military and hospital applications and their permissible concentrations according to EPA regulations.

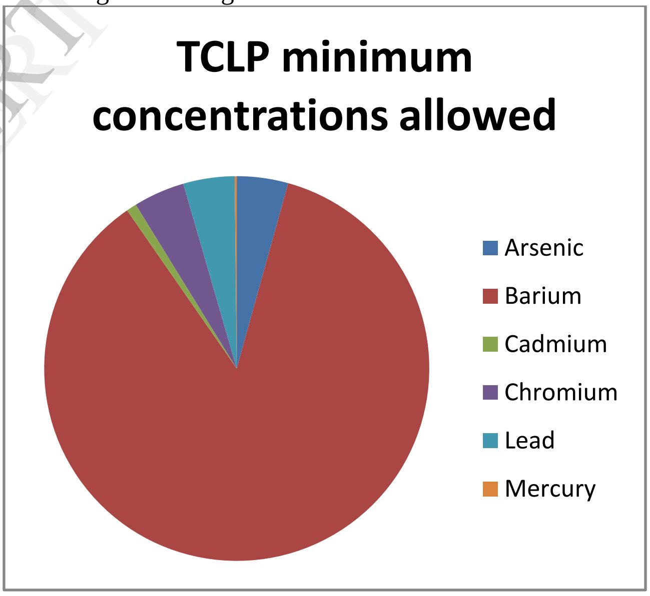


Fig.1 Hazardous Metals in Waste Stream and Permissible Concentrations

Two types of wastes are prevalent in a large city like Abuja, Nigeria. One is garbage from various houses and industries known as Municipal Solid Wastes (MSW). Secondly, there are also hazardous wastes from the hospitals and clinics as well as military establishments.Various waste treatment/disposal methodologies have been and continue to be evaluated for the environmental remediation of hazardous contaminated materials. Plasma arc technology has been identified as one safe and effective tool for the conversion of contaminated media into chemically inert solids no longer requiring disposal in EPA hazardous waste approved landfills.

This paper presents the role of thermal plasma process in the treatment of hazardous waste media.

II. THERMAL PLASMA ARC TECHNOLOGY

Plasma is an electrically conductive gas in which an important fraction of the atoms is ionized, so that the electrons and ions are separately free. Plasma may be created in the laboratory by a variety of ways, including passing a gas, which serves as a dielectric, between objects with large electrical potential differences, or by exposing gases to high temperatures, as in the case of arc welding or graphite electrode torches, [3]. The potential difference and subsequent electric field causes ionization of the gas and electrons are pulled toward the anode while the nucleus pulled towards cathode. The presence of this ionized gas allows the formation of an electric arc between the two electrodes, and the arc serves as a resistive heating element with the electric current creating heat which creates additional plasma that allows the arc to be sustained. In plasma arc technology, plasma torch is used to generate controllable plasma temperatures in the range from 1500°C to 10,000°C. Several processing benefits associated with plasma technology include high thermal efficiency (resulting in fast reaction kinetics); flexibility in choice of process gas environment; substantial waste volume reduction; high energy density, thus adequacy in utilizing smaller processing reactors; no material pretreatment is required; and the need for less pollution abatement equipment due to the lower demand for air and absence of fossil fuels.

Plasma gasification represents a clean and efficient option to manage waste in an environmentally responsible manner. The plasma gasification technology is ideally suited to process waste such as Municipal Solid Waste ("MSW"), common hazardous waste found in hospitals and military establishments, industrial waste, chemical waste, sediment sludge and biomass. It can also vitrify fly ash from incinerators and any other types of ash [3].

The strategy employed in plasma arc technology for the treatment of hazardous wastes involves subjecting contaminated material to the high temperatures of the plasma and chemically combining the non-volatile components into a matrix material, such as soil, so that the processed material, upon solidification, represents an inert, chemically stable material. The resulting matrices will immobilize the hazardous components and prevent them from further contamination of the environment. A schematic overview of several of the various stages involved in thermally treating wastes using plasma technology is shown in Fig. 2.A schematic of a generic plasma torch design is also shown in Fig. 3. The gas enters the torch body through a tube, travels up the length of the cathode and out through the anode throat, meanwhile passing through the generated arc and becoming plasma. In Fig. 4, a plasma torch which has been sectioned to reveal the internal configuration is shown.

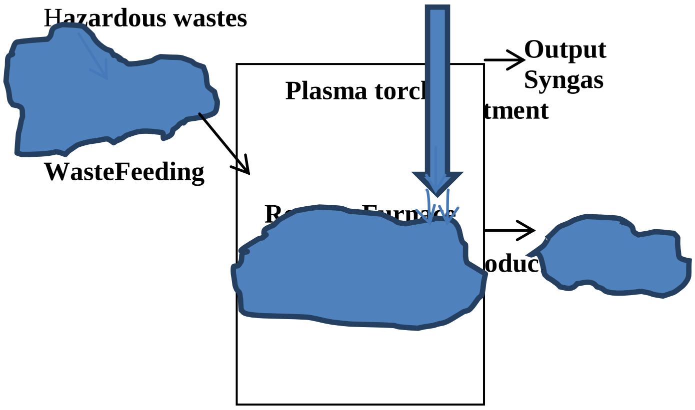


Fig. 2: Schematic Representation of Plasma arc Processing

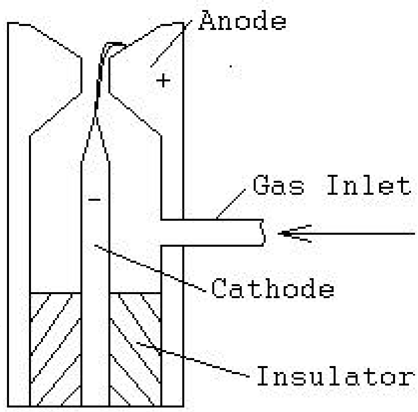
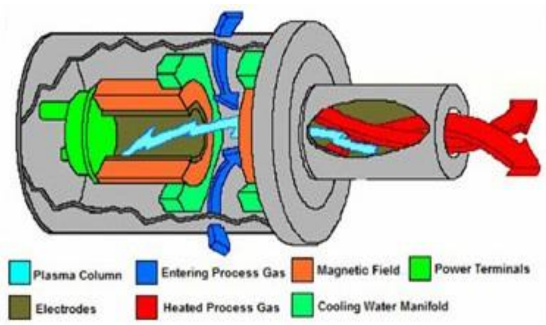


Fig. 3: A Generic Plasma Torch Design



Fig, 4: APlasma Torch Configuration.

During the actual processing of the waste, a plasma torch is used to generate the high temperatures (typically several thousand degrees Centigrade) necessary to break the chemical bonds present in the waste material, [2],[18]. The extremely intense energy produced by the torch is powerful enough to disintegrate the hazardous waste into its component elements. The subsequent reaction in the presence of controlled amount of oxygen produces syngas which leaves the furnace at the top for further treatment, and byproducts consisting of a vitrified glass-like substance which is collected at the bottom of the furnace and used as raw materials for construction, and also re-useable metals. The characteristics of the resulting vitrified product are a function of the torch-gas/furnaceenvironment, composition of the materials present within the plasma chamber, residence time of the waste during processing, and homogeneity of the treatment.

The plasma treated melt tapped at the bottom of the processing chamber, once cooled, the solidified mass, referred to as the slag, can be characterized as a vitrified, or glass-like rock. The potential of using this vitrified residue as various by-products such as aggregate, bricks, or gravel has been established [3]. More importantly, once processed by thermal plasma as described, the original hazardous waste now exists as a non-hazardous benign residue or slag. Various studies [4],[5],[6],[7],[8] have indicated the consistency of slag products to pass toxicity characteristic leaching procedure (TCLP)and durability testing.Highly volatile chemical species can escape out of the main reaction chamber before they are combined into the melt. Consequently, output-syngas treatment systems are used to trap particulate and destroy any residual organics before they are released into the atmosphere. However, the furnace is designed to operate under a slight negative pressure, minimizing the potential for escape of the product gas. In general terms a thermal plasma processing facility will have very low emissions of NOx, SOx, dioxins and furans, [3],[10].

III. MATERIALS AND METHODS

In Nigeria like most developing countries, hazardous wastes are commonly dumped in open dumps uncontrolled landfills along with other types of wastes such as MSW. These are sometimes openly burned, thereby releasing harmful gases to the atmosphere. The dangers of open dumping of hazardous wastes are numerous; health hazards, pollution of ground water, spread of infectious diseases, highly toxic smoke from burning and continuously smoldering fires, foul odors from decomposing refuse and emission of greenhouse methane gas.

Thermal Plasma process is an efficient and environmentally responsible form of thermal treatment [3],[9] of hazardous wastes which occurs in oxygen starved environment so that the waste is destroyed by the intense heat from plasma torch. The heart of the thermal plasma process is the “Thermal Plasma Furnace”, Fig.5; a vertical refractory lined vessel into which the waste material is introduced near the top along with metallurgical coke and limestone. Plasma torches are located near the bottom of the furnace and direct the high temperature process gas into a bed of coke at the bottom of the vessel. Air or oxygen is introduced through tuyres located above the torches. The high temperature process gas introduced through the torch raises the temperature of the coke bed to a very high level to provide a heat reservoir, and the process gas moves upward through the furnace vessel to vitrify the waste. The power of thermal plasma process makes it environmentally clean technique. Thermal Plasma Processesare being developed by many gas plasma technology companies for Waste destruction, [11]. The system will also handle such materials as steel beams and rebar; copper piping; steel, aluminum, and copper wire; and even concrete, stone, bricks, [13],[16].

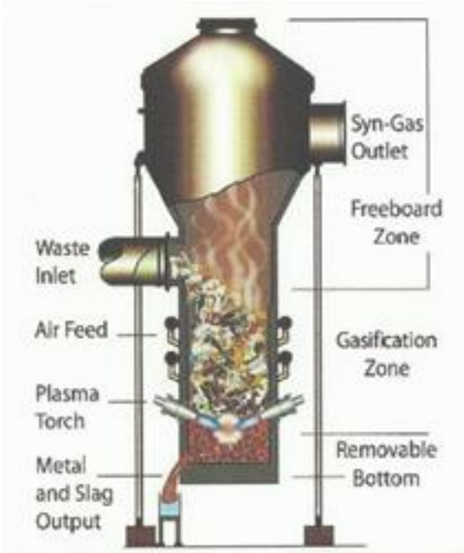


Fig. 5: Thermal Plasma Furnace

Additional heat is introduced from the reaction of the carbon in the waste with the oxygen introduced through the tuyres to produce carbon monoxide in the thermal plasma process. The hot product gas, passing upward though the wastes, breaks down organic compounds and dries the waste at the top of the furnace. As the waste moves downward through the furnace vessel, inorganic materials such as metal, glass and soil are melted and produce a two phase liquid stream consisting of recyclable metals and a vitrified glass-like residue that flows to the bottom of the vessel [3],[13]. Discharge of the molten material into water results in the formation of metal nodules and a coarse rock-like substance which is environmentally benign. The hot output syngas leaving at the top of the furnace is cooled and pass through cleaning and emission control processes to remove particulate matter and other toxic substances before passing to other desired conversion subsystems. Thus emissions to the environment are greatly reduced and kept under acceptable levels.

A. Measured Emissions Vs. Established Standards

University of California report [14] includes summaries of test results for plasma arc facilities that process circuit boards, medical waste, and MSW. Thermal Plasma process emission products measured included particulate matter, NOx, SOx, hydrochloric acid, and trace amounts of mercury and dioxins/furans; in all cases emissions were well below applicable standards (Tables 1-3).

TABLE 1 EPA VERIFICATION TESTING (2000) OF THERMAL PLASMA PROCESS FOR 10 TPD OF CIRCUITBOARDS.

Emissions (mg/N-M3@7%O2)	Measured	USEPA Standard
PM	3.3	20
HCL	6.6	40.6
NOx	74	308
Sox	-	85.7
Hg	0.0002	50
Dioxins/furans* (ng/N-m3)**	0.000013	13

** Dioxins and furans are compounds consisting of benzene rings, oxygen, and chlorine that are considered to betoxic or hazardous.*
*** One ng/N-m3 is one nanogram per normal cubic meter; Normal means at standard temperature and pressure.*

TABLE 2 EPA VERIFICATION TESTING (2000) OF THERMAL PLASMA PROCESS FOR 10 TPD OF MEDICAL WASTE,

Emissions (mg/N-M3@7%O2)	Measured	USEPA Standard
PM	<3.3	20
HCL	2.7	40.6
NOx	162	308
Sox	-	85.7
Hg	0.00067	50
Dioxins/furans* (ng/N-m3)**	0.0067	13

TABLE 3. RESULTS OF THIRD-PARTY DEMONSTRATION OF PLASCO ENERGY THERMAL PLASMA PROCESS GASIFICATION OF 110 TPD OF MSW, OTTAWA, CANADA

Emissions (mg/N-M3@7%O2)	Measured	EC 2000/76 Standard
PM	12.8	14
HCL	3.1	14
NOx	150	281
Sox	26	70
Hg	0.0002	14
Dioxins/furans* (ng/N-m3)**	0.009245	0.14

A. Measured Concentration of TLCP Vs. EPA Standard

Feasibility studies have been conducted on various military unique wastes. In addition to plasma treatment of soil contaminated with heavy metals and organic compounds, feasibility examinations of thermal batteries, incinerator ash, pyrotechnic smoke assemblies and sludge[17], have been conducted using Retech's Plasma Centrifugal Furnace (PCF) and Small Scale plasma arc centrifugal treatment (PACT) unit. In general, those items containing heavy metals were found to pass TCLP tests while organic destruction was successfully achieved through thermal plasma processing.The Georgia Tech PARF lab conducted several tests [15] using their prototype plasma gasification units. The main supplies of the furnaces were artificial combination of materials to simulate typical average constituents of MSW based on US EPA. For the Ex-Situ experiments the MSW constituents were used and for In Situ experiments, soil was added to the MSW constituents to simulate a real landfill. The summary of the PARF lab experiment results show that significant weight and volume reductions of MSW were achieved after plasma processing [15]. In addition:Toxicity Leaching text results for heavy metals (Arsenic, Barium, Cadmium, Chromium, Lead, Mercury, Selenium and Silver) present after thermal plasma process are below detectable levels (BDL) in both experiments, and also far below the permissible standards established by US EPA, Tables 4 and 5.

Again, Table-6 shows the output syngas compositions for experiment without soil and with soil respectively in parts per million:
Toxicity Leaching Tests Results: Tables 4 and 5 show the results of standard toxicity characteristics leaching procedure for experiment without soil and experiment with soil respectively.

TABLE 4. TOXICITY LEACHING RESULTS FOREXPERIMENT (WITHOUT SOIL)

Heavy Metal	Permissible Concentration (mg/l)	Measured Concentration (mg/l)
Arsenic	5.0	BDL (0.1)
Barium	100.0	0.47
Cadmium	1.0	BDL (0.1)
Chromium	5.0	BDL (0.1)
Lead	5.0	BDL (0.1)
Mercury	0.2	BDL (0.01)
Selenium	1.0	BDL (0.2)
Silver	5.0	BDL (0.1)

BDL = Below Detectable Level

TABLE 5. TOXICITY LEACHING RESULTS FOR (WITH SOIL)

Heavy Metal	Permissible Concentration (mg/l)	Measured Concentration (mg/l)
Arsenic	5.0	BDL (0.1)
Barium	100.0	BDL (0.1)
Cadmium	1.0	BDL (0.1)
Chromium	5.0	BDL (0.1)
Lead	5.0	BDL (0.1)
Mercury	0.2	BDL (0.01)
Selenium	1.0	BDL (0.2)
Silver	5.0	BDL (0.1)

BDL = Below Detectable Level

TABLE 6 OUTPUT GAS COMPOSITION

Output Gas	Ex-Situ Experiment without soil (PPM)	In-Situ Experiment with soil (PPM)
Hydrogen (H2)	>20,000	>20,000
Carbon Monoxide (CO)	100,000	>100,000
Carbon Dioxide (CO2)	100,000	90,000
Nitrogen Oxides (NOx)	<50	100
Hydrogen Sulfide (H2S)	100	80
Hydrogen Chloride (HCL)	<20	225
Hydrocarbons	>5,000	>4,500

PPM = parts per million.

Each plasma process application will have a differing environmental profile, [12] but in general terms a plasma gasification facility will have very low emissions of NOx, SOx, dioxins and furans.

IV. SUMMARY AND CONCLUSION

The environmental hazardsposed by hospital wastes, asbestos from demolished buildings, and hazardous wastes from military establishments are very serious. However, it is found that thermal plasma process is an effective tool for the treatment of all types of wastes. Plasma arc technology is a thermal treatment tool capable of safely and efficiently processing materials containing a large variety of environmental hazards such as heavy metals and asbestos. Utilization of this technology allows waste candidates to be safely transformed intonon-hazardous, vitrified glass-like rock suitable for use as construction aggregates; and cost effectively when other waste treatment alternatives fail. Plasma arc technology is undergoing continuous development to improve system reliability and versatility. Research continues in the areas of torch life performance, specifically in the development of longer-life electrodes, while continued development in effluent stream minimization is ongoing to increase technology public and regulatory acceptance. The extensive use of this technology by gas-plasmaorganizations, illustrate the potential and feasibility of the technology to meet the ever growing waste disposal needs of an environmentally conscious world community.

Design and implementation of a small scale plasma furnace have proven to be an effective tool for conducting preliminary or initial plasma runs under a more controlled environment with reduced operating costs. Having passed the environmental profile tests, thermal plasma process may in the near future qualify as a unique environmentally safe and economically viable tool for handling all types of waste media.

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