PLASMA ARC GASIFICATION- A WIN-WIN SOLUTION FOR HARNESSING ENERGY FROM VARIOUS SOLID AND HAZARDOUS WASTES

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ABSTRACT

Application of plasma physics to gasification in waste to energy (WTE) is one of the novel applications of a technology that was introduced several decades ago by Dr. S. L. Camacho. In this application, plasma a rc gasifies the carbon-based part of wide range of waste materials such as municipal solid waste, sludge, Hazardous wastes, used tires, agricultural waste, etc., and generates a synthetic gas which can be used to produce energy through reciprocating engine generators, gas turbines, and boilers. Syngas is a simple fuel gas comprised of carbon monoxide and hydrogen that can be combusted directly or refined into higher-grade fuels and chemicals. The non carbon- based part or inorganic part of the waste materials is being converted into vitrified glass and reusable metal. Slag is a glass-like substance which is the cooled remains of the melted waste; it is tightly bound, safe and suitable for use as a construction material. Plasma gasification technology has proven reliable at destroying hazardous waste and can help transform environmental liabilities into renewable energy assets. The aim of this study is to describe the basics of this technology, review the challenges and opportunities for implementation of plasma gas technology in WTE which can be useful to eliminate current barriers for developing such projects. In addition to this findings of several literatures are also discussed in this paper.

Keyword : *Plasma Arc Gasification, Syngas, vitrified slag, Solid & Hazardous Waste, Waste-to-Energy (WtE)*

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1. INTRODUCTION:

The increasing industrialization, urbanization and changes in the pattern of life, which accompany the process of economic growth, give rise to generation of increasing quantities of wastes leading to increased threats to the environment. In recent years, technologies have been developed that not only help in generating substantial quantity of decentralized energy but also in reducing the quantity of waste for its safe disposal. Every year, about 55 million tonnes of municipal solid waste (MSW) and 38 billion litres of sewage are generated in the urban areas of India. In addition, large quantities of solid and liquid wastes are generated by industries. Waste generation in India is expected to increase rapidly in the future. As more people migrate to urban areas and as incomes increase, consumption levels are likely to rise, as are rates of waste generation. It is estimated that the amount of waste generated in India will increase at a per capita rate of approximately 1-1.33% annually. This has significant impacts on the amount of land that is and will be needed for disposal, economic costs of collecting and transporting waste, and the environmental consequences of increased MSW generation levels. According to the Ministry of New and Renewable Energy (MNRE), there exists a potential of about 1700 MW from urban waste (1500 from MSW and 225 MW from sewage) and about 1300 MW from industrial waste. [13] The ministry is also actively promoting the generation of energy from waste, by providing subsidies and incentives for the projects. Indian Renewable Energy Development Agency (IREDA) estimates indicate that India has so far realized only about 2% of its waste-to-energy potential. With growing public awareness about sanitation and increasing pressure on the Government and urban local bodies to manage waste more efficiently, the Indian Waste-to-Energy Sector is poised to grow at a rapid pace in India in the years to come.

2. BENEFITS & RISKS OF WASTE-TO-ENERGY SYSTEMS

Waste-to-Energy technologies can solve two environmental issues at one stroke land use and pollution from landfills, and the well-known environmental dangers of fossil fuels. However, waste-to-energy systems can be expensive and often limited in the types waste of they can use efficiently; only some can be applied economically today. [16]The positive and negative sides of waste-to-energy include:

<u>BENEFITS:</u>

1. Decrease landfill burden
2. Decreased GHG emissions through offset of fossil fuels
3. Reliable, Local, Low carbon electricity that could fill response gaps of intermittent renewable like wind and solar
4. Local Energy source (fuels or electricity)

<u>RISKS:</u>

1. Distinctive to waste reduction and recycling programs
2. Increased air and water impacts with a disproportionate effect on already stresses urban areas
3. Financial risks for communities if technology is unreliable.
4. High cost may force scaling and lifetime of facilities that is contradictory to overall conservation goals; potentially exacerbated if the companies receive renewable credits.

3. VARIOUS THERMO-CHEMICAL WTE TECHNOLOGIES

Looking at thermo-chemical conversion processes, in which the energy content of waste is extracted and utilized by performing thermal treatments with high temperatures, the physico-chemical characteristics of feedstock strongly, determines the type of process. Main thermo chemical conversion methods are as given below:

1. **Incineration**
2. **Co-combustion**
3. **Gasification**
4. **Pyrolysis**
5. **Plasma gasification**

The thermal plasma gasification process represents significant advances over incineration. In order to understand the advantages of thermal plasma gasification; both the thermo-chemical processes are compared in table below.

Table 1. Comparison between incineration and thermal plasma gasification process or waste treatment [1,4]

Differential factors	**Incineration process**	**Thermal Plasma gasification process**
Definition	• Mass burning process	• Gasification process at elevated temperature
Amount of O_2	• Designed to maximize CO_2 & H_2O • Added large quantity of excess air • Oxidizing environment • Generating NO_x and SO_x	• Designed to maximize CO and H2 • Added limited quantity of O_2 • Reducing environment • Prohibiting the generation of NO_x and SO_x
Temperature	• Operating at temperature below ash melting point • Inorganic materials are converted into bottom ash and fly ash. • Bottom ash and fly ash are collected, treated and disposed as hazardous wastes	• Operating at temperature above ash melting point • Inorganic materials are converted in glassy slag and fine particulate matter • Slag is non leachable, non hazardous and suitable for construction material.

4. PLASMA GASIFICATION

Plasma Gasification is an emerging Thermo-chemical Waste-to-Energy conversion technology which converts organic content of waste streams into valuable synthesis gas & inorganic content into vitrified slag like glassy material at higher temperature & in oxygen starved environment by thermal plasma.

Plasma Gasification of wastes with low negative values has attracted interest as source of energy and considerable work has been done for application plasma gasification technology to Municipal Solid Waste.

Plasma technology appears to be probative technology for waste to energy conversion and can be easily adapted for the treatment of various kind wastes such as Municipal Solid Waste, Bio-Medical Waste, Hazardous Waste, chemical wastes, sediment sludge, biomass, heavy oil, used tires etc. [1]

Allothermal gasification allows processing of all kind of wastes which is totally independent from the oxidizing agent or equivalence ratio, LHV and the moisture content of the waste.

There are three main output streams of Plasma Gasification of waste as shown in following Figure 2 and details of each stream are as given below:

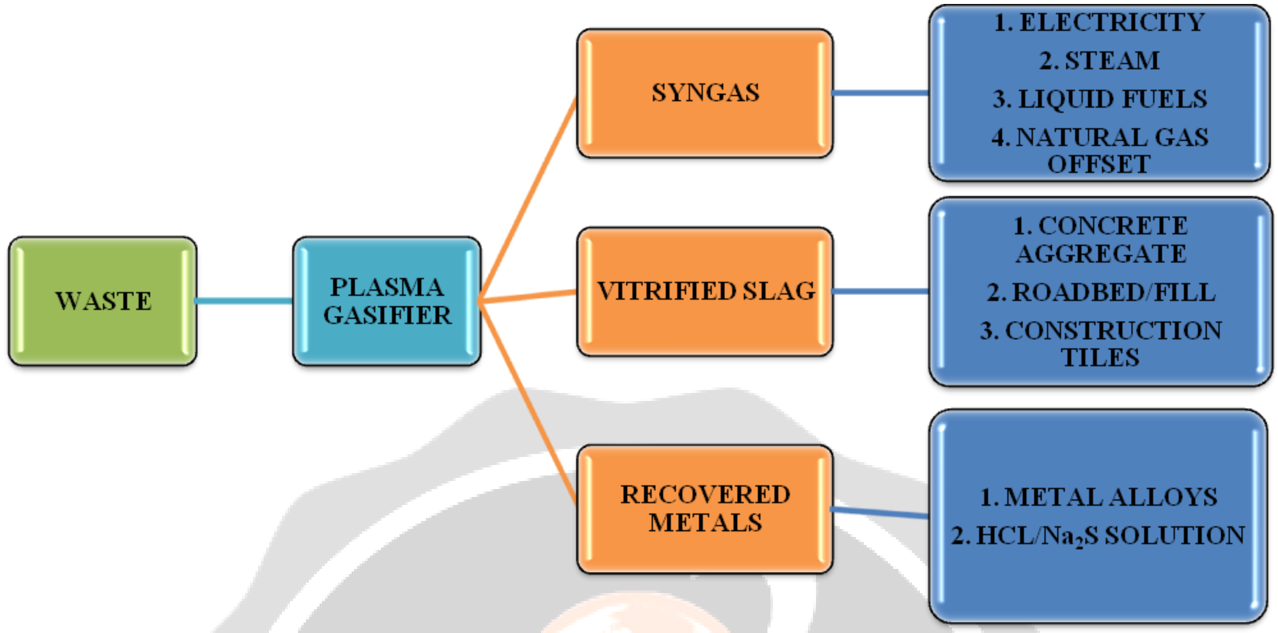

Figure 1. Process flow chart for Plasma Gasification Process

a. Syngas and its composition:

The oxygen contained in the oxidizing agent (i.e. Air, oxygen, CO_2 or steam of water) used for the gasification reacts with carbon to achieve a combustible gas, called "syngas". This syngas is mainly composed of Carbon Monoxide (CO) and Hydrogen (H_2) with low quantities of Carbon dioxide (CO_2), Water (H_2O), Methane (CH_4), Hydrogen sulphide (H_2S) and Ammonia (NH_3). [3]

Syngas is generally contaminated by undesired products such as particulate, tar, alkali metals, chloride and sulphide. The Syngas can be used for efficient production of energy due to its high calorific value content or as a raw material for the production of chemical substances (e.g., the production of methanol, Fischer Tropsch diesel, and hydrogen).

Syngas has heating value about one third to one sixth of natural gas and NHV of syngas lies in the range of 2 to 5 MJ/Nm^3.

b. Vitrified slag:

The inorganic part of waste stream i.e. glass, soil, sand etc. are being converted into vitrified slag like glassy material and metallic scrap is also molten in the reactor and at the bottom of the reactor two layered liquid formed which is then flow out and cooled down with water bath.

The vitrified slag should be inert for leaching processes and as a consequence applicable as, for example, a building material additive & construction material.

Removing the solid matrix of the vitrified slag from the bottom of the plasma reactor is known as Slag Matrix Tapping process. There are two modes of operation of plasma reactor:

i. Tapping mode

ii. Non tapping mode

Interval of tapping mode can be finalized based on inert level of waste cycle.

c. HCL/Na_2S Solution:

For the removal of HCN, SO_2, H_2S and residual HCl and HF from syngas an alkaline scrubber can be used which leads to formation of HCl and Na_2S solution like saleable by-products. Wet lime sorption is an alternative technology, resulting in the formation of $CaSO_3$, $Ca(CN)_2$ and CaS.

In India there are two hazardous waste disposal plants with a capacity of 72 tonnes/day and using Westinghouse Plasma Corporation's gasification technology and plasma torches to produce electricity are under operation in Pune and Nagpur, by SMS Infrastructures, India.

5. PLASMA GASIFIER:

Gasifier/Reactors can be constructed with different materials, which in turn decide the life of operation. To have longer working life, Stainless Steel (SS 304) is preferred as outer sheath with internal castable linings of different Refractory grades. The grades and heat transfer rates decides respective thickness. Alumina based cast able is used for the construction of plasma gasifier.

Waste from the waste feeding system enters into the reactor where high temperature created by plasma torch or electrodes dissociates waste into its basic elemental components. The bulk temperature inside the plasma reactor is maintained in the range of 1200 to 1400 ºC during normal conditions. The residence time of 2 to 3 seconds is normally being provided for synthesis gas to ensure complete destruction of waste in the plasma reactor. [15]

6. PLASMA TORCH AND GRAPHITE ELECTRODE

The graphite arc plasma process has three major advantages over the plasma torch technique.

1. Plasma torches need to be water-cooled meaning that 30% to 50% of the energy input is lost to the cooling water.
2. Plasma graphite arc designs have far greater scalability than torch-based systems. Torches are limited to a maximum 1.5MW to 2MW per torch, while graphite arc examples from the steel industry have capacities of 140MW to 150MW.
3. Finally, the up-front capital cost of a graphite arc system is much less i.e. one tenth of Plasma torch designs cost.

7. SYNGAS CLEANING AND TAR REMOVAL METHOD [9]

The plasma gasification plant needs to incorporate efficient gas cleaning equipment to meet contaminant tolerance limits for use in a gas engine or turbine. Five groups of contaminants are important: dust, heavy metals, sulphur compounds, nitrogen compounds (NH_3 and HCN) and halogens. These substances can be eliminated as follows:

Particulate matter can be removed by high temperature filtration, cyclones or with scrubbers. Filters or cyclones are advantageous since the particulates are removed as dry solid that can be injected into the slag for vitrification. Due to the high temperature, preliminary cooling may be required to avoid filter damage. In a water scrubber, dust is removed as slurry that has to be dewatered and dried before injection into the slag.

Metals bound to dust will be removed together with particulates Residual metal vapours are removed in an acid scrubber due to cooling and dissolving. The bulk quantity of HCl and HF and the NH3 can be removed in an acid scrubber. This may be a venture scrubber, to combine their removal with dust elimination. For the removal of HCN, SO_2, H_2S and residual HCl and HF, an alkaline scrubber can be used. Wet lime sorption is an alternative technology, resulting in the formation of $CaSO_3$, $Ca(CN)_2$ and CaS.

The risk for dioxin formation can be decreased by the high temperature removal of dust, because the presence of dust during cooling of the syngas is an important precursor of dioxins and furans. A proper design of the gasification plant should succeed in meeting the legislative levels for dioxins and furans in the exhaust gas of a gas engine.

Based on these measurements, a syngas cleaning system can be designed using available technologies. A purification system must have a quench and/or heat recovery to cool the gases, dust removal followed by acid and alkaline scrubbers. The feasibility of different technologies depends on the type of waste that is gasified and more specifically on the concentration of impurities in the waste.

8. POTENTIAL OF GHGs OTHER POLLUTANT EMISSION

Plasma gasification WTE facility avoids:

1. The release of methane that otherwise would be emitted when trash decomposes in landfills
2. The displacement of CO_2 that would have been emitted had the electricity been generated from fossil fuels such as coal

Plasma Gasification can reduce CO_2 emissions and offer benefits in the reduction of the generation of greenhouse gases ("GHG") and thus potentially generate carbon credits. Carbon credits are GHG emission reductions that are created when a project reduces or avoids the emissions of GHGs, relative to what would have been emitted under a 'business as usual' scenario.

There are a number of viable GHG reduction scenarios applicable to this emerging technology:

- Reduction of CO_2 and Nitrous Oxides: When plasma arc gasification synthesis gas is used for thermal and/or electrical energy production the amount of GHG's produced, is approximately one half of that produced by the combustion of coal and/or fuel oil for an equivalent amount of energy produced.
- Avoidance of land filling materials containing organic constituents avoids the production of methane which is has a Global Warming Potential (GWP) that is 22 times that of CO_2.

Carbon credits are measured in units of certified emission reductions (CERs). Each CER is equivalent to one ton of carbon dioxide reduction. Depending on the 'business as usual scenario', the waste streams being processed and the type of Plasma Gasification system, hundreds to thousands of CERs can be generated in a given year. [14]

This waste conversion and electric power generating system operates on the principle of environment friendly waste disposal and sustainable generation of renewable energy. In general terms a thermal plasma gasification facility has very low emissions of NO_x, SO_x, dioxins and furans and particulate matter. The other pollutants such as Dioxins/Furans if generated; will be less than 0.01 Ng/Nm^3, Sulphur reports as Hydrogen Sulphide (H_2S) which is easier to clean than So_x using scrubbing liquid and tars are cracked prior to leaving the Gasifier.[1]

Graphical representation of potential of various pollutant emission from gasification, incineration and landfill sites is shown in figure below:

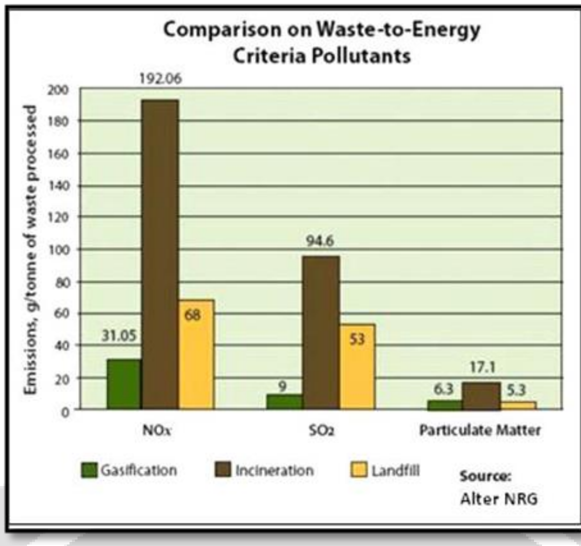

Figure 2. Comparison on Waste-to-Energy Criteria Pollutants

9. FINDINGS:

By reviewing various literatures it is concluded that the Plasma Arc Gasification is an emerging technology to harness the untapped energy from waste. Besides the technical advantages, there are clear environmental benefits.

Plasma gasification process can reduce the weight of Municipal Solid waste by more than 80% and volume of organic matter can be reduced by more than 95% [5]

Moreover, it does not differentiate among the waste to be treated that means all kind of wastes can be fed to reactor without segregation.

The one and only drawback of this technology is comparatively higher electric power input is required (i.e. around 40% of electricity being generated by waste conversion) for waste conversion into syngas and vitrified slag; depending on characteristics of waste to be converted. However, no technology is fully viable without government support and financial aid.

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