1. General

Plasma refers to every gas of which at least a percentage of its atoms or molecules is partially or totally ionized. In a plasma state of matter, the free electrons occur at reasonably high concentrations and the charges of electrons are balanced by positive ions. As a result, plasma is quasi-neutral. It is generated from electric discharges, e.g. from the passage of current (continuous, alternate or high frequency) through the gas and from the use of the dissipation of resistive energy in order to make the gas sufficiently hot. Plasma is characterized as the fourth state of matter and differs from the ideal gases, because it is characterized by 'collective phenomena'. 'Collective phenomena' originate from the wide range of Coulomb forces. As a result, the charged particles do not interact only with neighboring particles through collisions, but they also bear the influence of an average electromagnetic field, which is generated by the rest charges. In a large number of phenomena, collisions do not play important role, as 'collective phenomena' take place much faster than the characteristic collision time (Blachos, 2000).

Plasma Technology can be used as a tool for green chemistry and waste management (Mollah et al., 2000). Thermal plasmas have the potential to play an important role in a variety of chemical processes. They are characterized by high electron density and low electron energy. Compared to most gases even at elevated temperatures and pressures, the chemical reactivity and quenching rates that are characteristic of these plasmas is far greater. Plasma technology is very drastic due to the presence of highly reactive atomic and ionic species and the achievement of higher temperatures in comparison with other thermal methods. In fact, the extremely high temperatures (several thousands degrees in Celsius scale) occur only in the core of the plasma, while the temperature decreases substantially in the marginal zones (Gomez et al., 2009).

Five distinct categories of processes are used as the basis for the plasma systems catering for waste management (Juniper, 2006). These are:

- Plasma pyrolysis (Huang & Tang, 2007; Sheng et al., 2008)
- Plasma combustion (also called plasma incineration or plasma oxidation)
- Plasma vitrification
- Plasma gasification in two different variants (Malkow, 2004)
- Plasma polishing using plasma to clean off-gases

Plasma gasification is the most common plasma process. It is an advanced gasification process which is performed in an oxygen-starved environment to decompose organic solid waste into its basic molecular structure. Plasma gasification does not combust the waste as incinerators do. It converts the organic waste into a fuel gas that still contains all the chemical and heat energy from the waste. Also, it converts the inorganic waste into an inert vitrified glass (Moustakas et al., 2005; Moustakas et al., 2008).

Mixed solid waste is shredded and fed into a reactor where an electric discharge similar to a lightning (the plasma) converts the organic fraction into synthesis gas and the inorganic fraction into molten slag. Typically temperatures are greater than 7,000°F achieving complete conversion of carbon-based materials, including tars, oils, and char, to syngas composed primarily of H_2 and CO, while the inorganic materials are converted to a solid, vitreous slag. The syngas can be utilized in boilers, gas turbines, or internal combustion engines to generate electricity while the slag is inert and can be used as gravel.

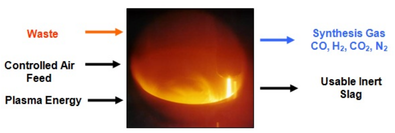
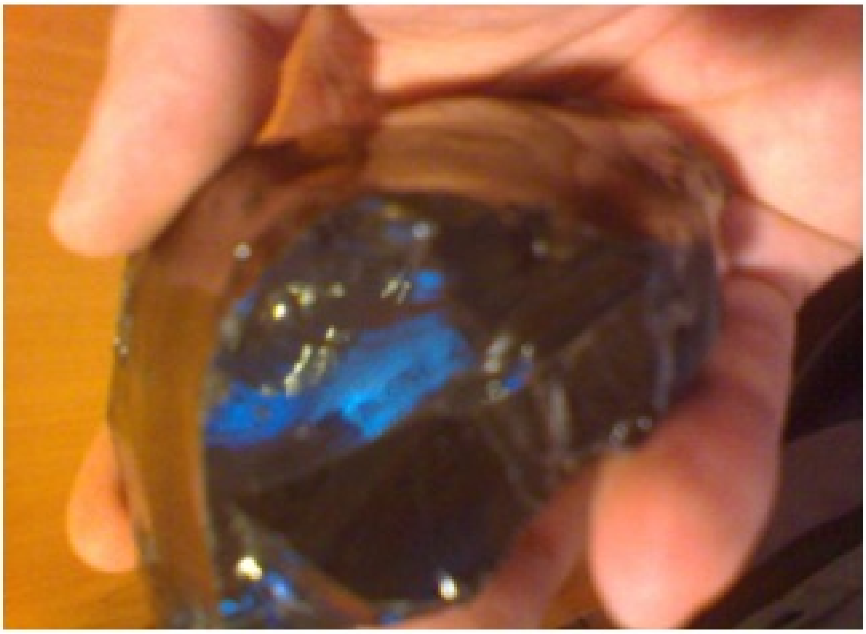


Figure 1: Plasma gasification process flow chart

Picture 1: Molten slag pouring from plasma waste gasification reactor (Pyrogenesis Inc, Montreal, Canada)

The advantages of the process include: Good environmental performance, production of about 400 KWh net of electricity per tonne of waste treated, no by-products going to landfill.



Picture 2: Final inert slag residue can be used in construction applicati

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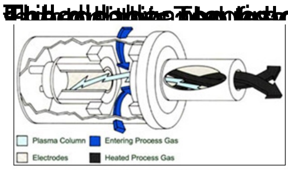

Figure 2: Plasma torch operation

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2. Mass and energy balances

In general, the mass and energy balances have similarities with the respective ones referring to gasification. A typical energy balance assumes that from one tonne of waste treated more than 400 KWh net electricity is produced.

3. Market potential for products

There are a number of applications for the plasma gasification syngas. For example, it can be utilized as fuel source to produce electric power (e.g. in a simplified steam-cycle configuration consisting of a conventional boiler/steam generator with steam turbine) or in a gas engine, configured to accept lower heat value gas. The gas can be used in a gas turbine, both in simple cycle and in combined cycle operations. It can also be used as a feedstock for chemical processes, e.g. the production of methanol.

The use of lower heat value plasma gasification syngas as a fuel source for gas engines has been successfully demonstrated with syngas generated from various feedstocks, including the gasification of biomass. Other applications for the utilization of the plasma gasification syngas are as follows: separation of hydrogen from the syngas, which can provide an excellent source of hydrogen for use with fuel cells, using the syngas as a feedstock for the production of liquid fuels, such as ethanol.

Applications for the glassy product include roadbed/fill construction and concrete aggregate. Any reclaimed valuable metal could be sold to metal dealers and processors. Metal alloy is bought and sold based on a commodity-based pricing system.

4. Environmental impacts

Plasma gasification uses an external heat source to gasify the waste. Almost all of the carbon is converted to fuel gas. Plasma gasification is the closest technology available to pure gasification. Because of the temperatures and drastic conditions involved all the tars, char and dioxins are broken down. The exit gas from the reactor is cleaner and there is no ash at the bottom of the reactor, while there are no by-products that end up to landfills provided that there are available markets for the produced slag. On the other hand, the use of plasma gasification processes reduce methane emissions produced from the disposal to landfill sites, while as a waste to energy treatment method, enables the displacement of CO_2 that would have been emitted had the electricity been generated from fossil fuels.

5. Economic data

According to the Carbon Finance Unit of the World Bank in 2008, the capital cost of a plasma gasification system with a capacity of 900 tonnes per day is 40-60 € /tonne, while the operation and maintenance cost is 55-100 € /tonne. Nevertheless, most sources estimate that the cost is a little bit higher than other thermal methods due to the use of electrical energy.

6. Applicability in the target area

The application potential of gasification and plasma gasification is also considered high, since these methods have recently proved that they are effective and flexible, since they can also be used for the treatment of other waste streams (e.g. sludge, hospital waste, etc.) apart from municipal waste. That is why the gasification practices are considered as suitable alternative especially in the case of isolated areas, such as islands. The relevant cost is similar to that of other thermal management practices, higher than that of biological options, the relevant land demand is limited and the energy yield is also considered of vital importance. The experience from the operation of such plants is less than that from incineration units.

The first attempt to apply gasification process in the target region and more specifically in Greece was made he National Technical University of Athens, with a unit that was installed in Mykonos in order to treat all types of waste generated on the island with emphasis on municipal solid waste. The unit had been initially designed and developed in the framework of the LIFE project entitled: “Development of a demonstration plasma gasification / vitrification unit for the treatment of hazardous wastes” and later was modified in order to cater for the treatment of municipal solid waste, too. The scope was to investigate the use of this innovative technique in an isolated area like an island in order to provide a solution to the overall management of waste. General views of the whole demonstration facility are available below:

Picture 3: General view of the demonstration gasification / vitrification unit

Picture 4: Another general view of the demonstration gasification / vitrification unit

The primary waste feeding system consists of a hopper intended for feed of solid material having maximum moisture content of 50% and a maximum particle size of 2.5 cm. The screw conveyor solid feeder has a maximum capacity of about 85 kg/h of waste and the feeding capacity varies depending on the feed waste bulk density. The feed rate is adjustable by varying the speed of the screw conveyor. Waste is manually loaded into the hopper connected to the screw conveyor. The feed rate is continuous and very steady, compared to a hydraulic feeder.

Waste is fed from a hopper through a screw feeder to the top of the furnace and dropping down is passing through the very hot and free of oxygen region between the two electrodes.

Picture 5: Feeding system

The furnace is comprised of a crucible, with approximately 130 litters capacity. It also includes a start-up natural gas burner for preheating and idle operation, a port for gasification air injection, a water-cooling mechanism for the graphite electrodes, an external surface water-cooling for the furnace walls and a tapping hole for periodical or continuous slag removal. During the operation of the plasma unit, the bottom part of the furnace contains the molten slag, while the upper section of it contains the process gases and is lined with a suitable high-temperature refractory. The required gasification air fed to the furnace is supplied by a compressed air system. Adjusting the valves on the compressed air line can control the flow rate.

Picture 6: Gasification / vitrification furnace

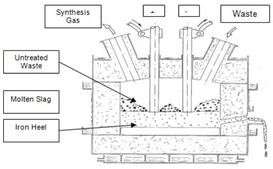

Figure 3: Plasma Gasification / Vitrification Process

Picture 7: Cyclone

Picture 8: Secondary Combustion Cham

Picture 9: Quench Vessel

Picture 10: Scrubber

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