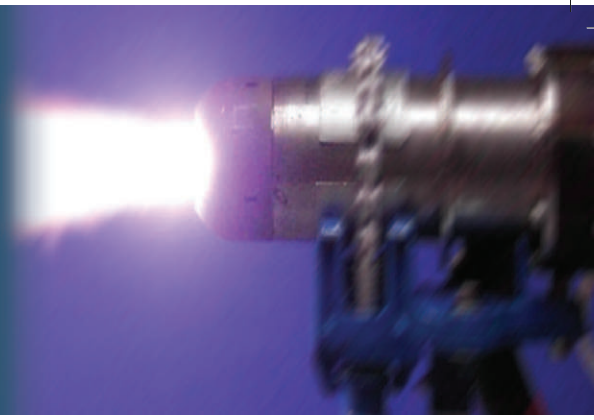


by Jean-René Gagnon and Pierre Carabin

A torch to light the way

Plasma gasification technology in waste treatment

Plasma gasification achieves a very high waste volume reduction regardless of waste type, requires no fossil fuel input, and results in lower pollution than conventional incineration. It produces two useful by-products – inert slag for use as a construction material, and syngas for power generation. Currently with limited commercial use, there is potential for widening its foothold in waste management.

> ‘Plasma gasification uses electricity to convert waste into a fuel gas and an inert rock’

Thermal treatment of waste is once again attracting increasing attention as a viable alternative to landfill disposal. It reduces the volume of solid waste significantly but suffers from a bad reputation with the public, representing one of the top industries no one wants ‘in their backyard’. Some of this fear stems from a lack of information about the process, but more justified concerns over emissions remain. Depending on the type and age of technology used, potential emissions include dangerous organic molecules such as furans and dioxins, incomplete combustion products such as carbon monoxide, large amounts of particulates, as well as acid rain precursors such as nitrogen oxides and sulphurous compounds. Moreover, the management of the large amounts of bottom ash and potentially toxic fly-ash can cause significant disposal problems in countries where landfill space is scarce. The good news is that the technologies needed to remove the pollutants from the stack gas and clean the ashes are improving rapidly. Yet they remain quite expensive. A new method that can destroy waste at high temperatures is plasma gasification, which uses electricity to convert waste into a fuel gas and an inert rock.

What is plasma?

Plasma is an ionized gas that conducts electricity. Many types of gases can be used, such as argon, helium, methane and steam. For waste gasification applications, air is the most commonly used gas. In order for air to conduct electricity, it must be subjected to a large differential in electrical potential. This is done between two electrodes which are separated by air. When this potential is large enough, electrons can be pulled from the normally neutral molecules in the air. These electrons then move with the electric field and impact other molecules, releasing more free electrons at an exponential rate. This phenomenon is called an electron cascade, and once enough electrons are moving with the electric field, an arc is created between the electrodes. All of this happens within a fraction of a second.

Viewed as an electrical circuit, the air gap where the arc is created can be seen as a resistance. While going through this resistance, the electrical current releases large amounts of heat. Several technologies have been developed to use this source of heat which can reach temperatures from 5000ºC to 10,000ºC. The following section describes two of these technologies – the plasma torch and the transferred-arc graphite electrodes.

Plasma can be used to treat waste of varying quality, such as waste with a high concentration of inorganic material and a very low heating value. This is because most of the heat necessary for the gasification comes from the plasma and not from the oxidation of the waste.

The plasma torch

A basic plasma torch contains two electrodes – a cathode and an anode – which are typically made of copper, with a small amount of rare metals such as tungsten or hafnium. A gas flows between these two electrodes while the voltage is applied. Once 'sparked', an arc is created. High-temperature gas is directed out of the torch tip and stretches across the electric arc, where it makes contact with the waste to be destroyed. Simply put, the plasma torch works like a hair dryer, where the electric arc acts as the heating element and air is pushed through this element, which heats the air up to very high temperatures of more than 5000ºC. The flame that exits the torch is referred to as the plasma 'plume'.

The plasma torch works like a hair dryer, but heats the air to temperatures of over 5000ºC

The plasma torch can be used in an oxygen-deprived environment to gasify waste, creating a syngas from the organic components. It can also be used to heat up the inorganic components of waste to a high temperature, therefore melting or vitrifying the ash to an inert glassy material, also known as slag.

Graphite electrodes

The graphite-arc plasma system uses the energy available in an electrical arc by transferring the energy directly to the material that will be destroyed. A high current (ranging from a few hundred amps to several thousand amps) is directed through long cylindrical graphite electrodes into a furnace,

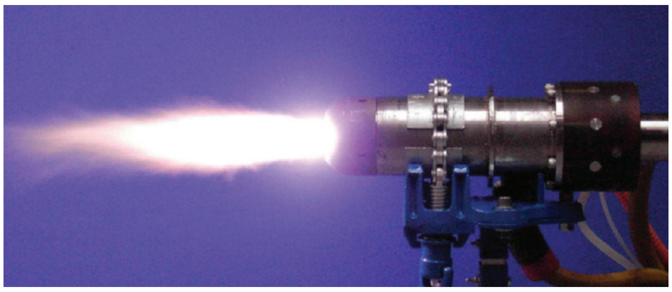
Vitrification

Vitrification is the process in which inorganic components such as silicates melt into a viscous liquid which traps heavy metals into a solid matrix once solidified. The vitrification process converts the inorganic components into a solid rock which will not leach and can therefore be used as construction material. Since the vitrified silicate rock typically has a density of 2.5 times the density of water compared with less than 0.5 for ash from more conventional incinerators, the process of vitrification allows for a significant volume reduction, typically of more than 5:1 for ash and more than 50:1 for solid waste.

lined with refractory material. The electrical energy typically jumps from an electrode to another (non-transferred-arc mode) or from an electrode to the waste (transferred-arc mode), crossing air gaps in the process. As with the torch, the arcing generates tremendous heat which serves to heat the waste. The temperature in one of these furnaces can attain 1500ºC. At this temperature, the inorganic portion of the waste is vitrified and it is this molten pool of hot slag at the bottom of the furnace that serves as a hot mass of energy, allowing waste to be processed at high feed rates.

The chemistry of gasification and combustion

Plasma can be used in gasification to break down waste into a gas. Although gasifiers such as fluidized-bed systems have



A plasma plume created by a 150 kW plasma torch

existed for many years, the heat in plasma allows the use of low-energy fuels, such as household and industrial waste that often cannot sustain their own gasification without additional fuel.

Gasification is the thermal degradation of carbon-based organic materials into a gas at high temperatures (400º–1500ºC) while inorganic components turn either into a solid char or liquid slag. This process is carried out in an oxygen-starved environment, preventing the combustion of carbon to CO_2. (When no oxygen is present at all, the process of breaking down large molecules into smaller ones by heat, not by flame, is called pyrolysis. When small amounts of sub-stochiometric oxygen are present, the process is called gasification.)

The gas produced by gasification – called a syngas, synthesis gas or producer gas –consists mainly of CO and H_2 which are both in a reduced state (they are essentially a fuel) and can undergo further oxidation (combustion) to release energy.

There are several advantages to producing a syngas rather than a fully combusted gas. For the same amount of waste, gasification will produce a smaller volume of gas since no fossil fuels are burned to generate heat and there is no need for excess oxygen as in most other thermal treatment processes. Of course, a smaller volume of gas costs less to clean. Also, a clean syngas can be turned into energy quite efficiently using either a turbine or an internal combustion engine. The syngas can also be converted to other gases or chemicals, such as methane (similar to natural gas), hydrogen or methanol.

The gas produced by thermal treatment of waste is typically subject to local and national emissions regulations. The main components being regulated worldwide are acid gases, carbon monoxide, nitrogen oxides, particulates as well as dioxins and furans. In North America and Europe, these standards are becoming increasingly strict. For example, in December 2005 the US EPA issued a new standard for the incineration of non-hazardous solid waste (40 CFR Part 60) which reduces, for example, the emission limits for SO_2 from 30 ppm to 3.1 ppm and NOx limits from 500 ppm to 103 ppm.

Great promise

Because of their high cost, plasma systems have so far been used primarily for the vitrification of high-end waste such as military and low-level radioactive waste. Some demonstration plants have also been developed and operated at relatively small scales. As plasma systems become more accepted and their design is simplified, their use will become more widespread. Plasma systems promise to offer a viable alternative to landfilling and conventional incineration, with lower air pollution and virtually no by-products requiring final disposal. The syngas produced can be used for energy generation or can be converted for other applications, while the small amounts of vitrified solid can be used in the construction industry.

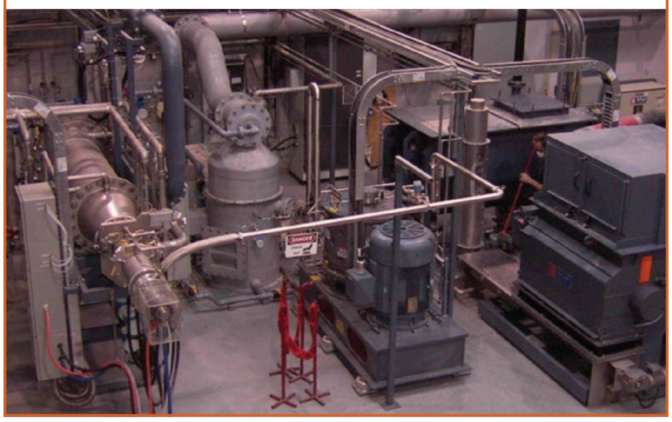
Plasma waste treatment in practice: PyroGenesis at sea

A demonstration prototype developed in collaboration with the US Navy, the Plasma Arc Waste Destruction System (PAWDS) aims to destroy waste using the smallest amount of space possible. The result is a compact system, with no refractory material and which occupies less than 100 m^2 (1000 ft^2) of a single deck.

The PAWDS system can destroy all sorts of wastes such as paper, cardboard, plastic, wood and textiles. The waste is first shredded into approximately 2-inch (5 cm) particles and is mixed together in a ribbon mixer. It is then pulverized into a fine dust by a powerful mill and fed in front of the plasma torch where it is sequentially gasified and combusted.

An identical system, installed commercially onboard the Carnival Cruise Lines' M.S. Fantasy, has destroyed well over 1,000,000 pounds (450,000 kg) of waste during the last two years. The PAWDS system can also destroy sludge oil with up to 50% moisture content at the rate of up to 200 litres per hour. Because the plasma torch is an independent source of heat, the performance of the system is not affected by the heating value of the oil and, as such, oil with high water content can be treated easily.

The PAWDS system at PyroGenesis in Montreal, Canada



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