

Plasma pyrolysis of medical waste

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Plasma pyrolysis is a state-of-the-art technology for safe disposal of medical waste. It is an environment-friendly technology, which converts organic waste into commercially useful by-products. The intense heat generated by the plasma enables it to dispose all types of waste including municipal solid waste, biomedical waste and hazardous waste in a safe and reliable manner. Medical waste is pyrolyzed into CO, H₂, and hydrocarbons when it comes in contact with the plasma-arc. These gases are burned and produce a high temperature (around 1200°C). In the plasma pyrolysis process, the hot gases are quenched from 500° to 70°C to avoid recombination reactions of gaseous molecules that inhibit the formation of dioxins and furans. The gas analysis results reveal that toxic gases found after the combustion are well within the limit of the Central Pollution Control Board's emission standards. The plasma environment kills thermally-stable bacteria. A comparison of this technology with conventional waste-treatment technologies is made in this article. The process economics is discussed in brief. The plasma pyrolysis technology has been indigenously developed at the Facilitation Centre for Industrial Plasma Technologies, Institute for Plasma Research, Gandhinagar.

Introduction

PUBLIC concern over disposal and treatment of medical waste has resulted in increasing regulations and court actions. The phenomenal increase in the quantity of medical wastes generated in the hospitals is attributed to the growing use of disposables, as precautions against exposure to infectious diseases such as AIDS, and in general, to the increase in medical and public health facilities. The generators are included in hospitals, clinics and medical research facilities. A rule of the thumb for medical waste production in affluent countries seems to be 1 kg per bed per 8 h shift. Hospitals, other health-care units and research facilities in our country produce millions of tons of waste every year. This waste is often mixed with municipal solid waste dumped in landfills, where it can contribute to environmental pollution.

There are four primary ways to manage hospital waste: landfilling, source reduction, recycling and incineration. Historically, landfilling was the most preferred means of disposal of medical waste. Public opposition and positive

correlation with groundwater contamination have resulted in this option steadily going out of favour. In many countries, medical waste can no longer be disposed in landfills, unless it is so thoroughly disinfected as to pose no risk to human health. This is very expensive. Burning the waste material in open air can never be complete, with small quantities of many organic and chlorinated organic compounds as well as pathogens surviving. This will lead to dispersal of dangerous diseases. Incineration is currently used to destroy hospital waste, especially biomedical waste and hazardous chemical waste by reducing the volume and destroying some harmful constituents. The process has many drawbacks, which are described below. Disposal of hospital waste in an environmentally acceptable manner is thus a critical necessity.

Economics of medical waste disposal is also staggering. Associated with this is the increasing cost of safe disposal, estimated in the US at 100–500 dollars per ton. The medical waste disposal market is pegged at \$ 1 billion annually.

Medical waste

Hospitals, health-care units, maternity and nursing homes, and research facilities produce large quantities of hazardous waste. These include human anatomical waste (tissues, organs), blood and body fluid, microbiological waste, animal waste, highly infectious waste, discarded medicines, disposables, etc. Based on occupancy ratio of the hospitals, 700 g/day waste is generated per bed in hospitals at Ahmedabad¹.

Medical waste has been classified into two categories: (i) general waste, which is not potentially dangerous and does not require special handling and disposal, and (ii) hazardous waste, which requires special handling, treatment and disposal, usually according to specific regulations and guidelines. The latter may pose potential health, safety or environmental hazards. There are three categories of hazardous waste – chemical waste, infectious waste and radioactive waste. Infectious waste, known as red-bag waste, includes materials considered to be potential health hazards because of possible contamination with pathogenic micro-organisms. Typical medical waste components are shown in Table 1.

Hospital waste treatment in India

Except for a few hospitals, waste is mostly dumped in the open space enabling ragpickers to collect contaminated

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syringes, cotton, plastics, etc. In many hospitals, medical waste is burnt at dumpsites in an open environment. Landfills used to dump contaminated waste and toxic residue from incinerators, are quite often designed poorly and can pollute ground-water. Oil-fired and electric incinerators are used for the destruction of waste work at low temperature (~ 400–700°C). The alarming fact is that the statutory secondary treatment of gases at 1100°C is rarely done. In addition, many small hospitals provide contract to private agencies for the disposal of their waste, and do not even know whether it is destroyed properly or not. Microwave systems are available at two or three places.

Incineration and its drawback

Incineration is merely the burning of waste material in the presence of oxygen. Incinerators have significant air emission control problems. It has been found in a survey conducted in Delhi that incinerators work at low temperatures (400–500°C)². There is a possibility of the survival of pathogens if the incineration is incomplete or done at low temperature. Airflow that is in excess of the stoichiometric requirement for combustion is essential for the incinerator to enhance the combustion process. The demand for excess airflow limits the temperature that is achievable. Due to insufficient temperature generated in the process chamber, incinerators produce extremely toxic products like furanes and dioxins. This can cause air pollution or the toxic pollutants can remain in the bottom ash, eventually finding their way into landfills.

Non-incineration methods

Autoclaves and hydroclaves are commonly used to sterilize waste, which at a later stage is burnt in an incinerator. Both these techniques employ steam sterilization with direct and indirect heating methods. Handling of contaminated waste and use of incinerator for complete disposal make these processes tedious. Microwave disinfection is a non-incineration process that is used for sterilization (disinfection) of medical waste. Subsequently, the sterilized waste is either dumped along with the municipal waste or is treated by incinerators. The major disadvantage of the process is that the reduction of waste volume is not much. Microwave technique also requires

high investment. The process also exposes the workers to a contaminated shredder.

Plasma as the ultimate destroyer

Plasma-arc employing carbon electrodes was first used in 1960s as a source of intense heat. The short lifetime of the electrodes was a major impediment in the successful development of this technology. With rapid developments in plasma sources, plasma technology was applied to destroy highly toxic compounds and to modify refractory compounds in an environment-friendly way. The abundant ultraviolet radiation in thermal plasma can dehydrogenate organic chlorine. The reactors can process gaseous, liquid and solid materials.

The workhorse of plasma-based waste destruction technology is the plasma torch³. Plasma torches are electrical discharge plasma sources with the plasma being extracted as a jet through an opening in the electrode and out of the confines of the cathode–anode space. The inherent thermal and electromagnetic instabilities of the arc column are stabilized by forced gas flow along the current path or by interaction with a guiding wall or by external magnetic fields. DC, rf and microwave power sources can be used to produce the arc.

The driver for the development of plasma torches was the space race in the 1960s. Missiles re-entering the atmosphere create shock-ionized air plasma. Laboratory simulation of these conditions was necessary for the development of materials capable of withstanding the searing heat of the re-entry plasma. Arc systems were designed to generate the re-entry conditions using high enthalpy gases at high stagnation pressures. Many of the present-day plasma torches are derivatives of the plasma jet sources built for this application. Gases can be heated rapidly to thousands of degrees by striking an arc discharge between suitably designed anode and cathode in the plasma torch. The electrodes are energized by specially designed power supply.

Brief historical review

Plasma-arc technology was developed and employed in the metallurgy industry during the late 1800s to provide extremely high temperatures. During the early 1900s, plasma heaters were used in the chemical industry to manufacture acetylene from natural gas. Plasma-arc heaters received renewed attention when the United States NASA Space programme, during the early 1960s, evaluated and selected plasma-arc heating technology for simulating and recreating the extreme high heat of re-entry into the earth's dense atmosphere encountered by spacecraft from orbit. Subsequently, small-scale plasma heater processes were built and tested during the 1970s. Large-scale industrial plants were built and commissioned during 1980s.

Table 1. Typical hospital waste components

Waste	Weight (%)
Paper and cloth items	50–70%
Plastic	20–60%
Glassware	10–20%
Fluid	1–10%

Since then, various companies like Pyrolysis Systems Inc., Canada, Siemens, Germany, Plasma Energy Applied Technology Inc., USA, Plasmapole, France, etc. are active in the development of plasma systems using plasma-arc technology. Westinghouse Environmental Services, USA demonstrated a prototype unit of dc arc incinerator in 1987 (ref. 4). Electrical Industry Research Institute in Hungary developed a plasma reactor pilot plant in 1988, for the destruction of halogenated chemical-industry waste⁵. Retech Incorporation of California and US Department of Energy initiated a collaborative programme to destroy a variety of waste using plasma-arc technologies in 1989 and later, in 1994, developed a rotating plasma furnace⁶⁻¹¹. Plascon In-Flight Plasma Arc System is designed to treat chlorinated organic compounds⁹. Destruction efficiencies of better than 99.99% were achieved for organic contaminants. Plascon system yielded very high destruction performance and released dioxins and furans in the range of 0.005–0.009 ng/m³, which is well below the set limit of environmental standard in the world. Halogenated organic compounds were treated in hydrogen plasma, which was found suitable for the elimination of halogenated compounds and soot particles¹². In a pilot-scale research furnace at MIT, a 10,000°C plasma-arc was used to melt waste material into a lava-like liquid, which then solidified into a stable black glass that could be safely used as a construction material¹³. Leading companies in the field of plasma technology have tested, treated and analysed hundreds of waste streams at industrial capacity over many years. The waste streams, which were successfully treated and disposed by plasma-arc technologies, include: Municipal solid waste, incineration ash, automobile tires, waste coal, sludges, polychlorinated biphenyl, hazardous fly ash, medical waste, paints, solvents, contaminated landfill material, low-level radioactive waste, etc.

The majority of plants utilizing the different plasma torches and plasma-heating system have been in use typically 24 h a day year-round at industrial capacity. For example, a plasma plant in Defiance, Ohio, employs six 2.5 megawatt torches simultaneously, handling over 40 tons per hour scrap metals. The CSIRO/Siddons Ramset Ltd's Plascon, Retech, Westinghouse Plasma Inc., Plasma Energy Corporation and various other companies design and develop large size, custom-made, plasma waste-treatment systems. Currently-implemented projects clearly demonstrate that the plasma-arc technology is a well-proven, well-demonstrated, commercially viable technology, which is utilized in industrial plants to treat different waste materials, worldwide.

Plasma pyrolysis

Plasma, the state of matter formed by removing the bound electrons from atoms, is an electrically conducting

fluid consisting of charged and neutral particles. The charged particles have high kinetic energies. When the ionized species in the plasma recombine with the stripped electrons, significant amounts of energy in the form of ultraviolet radiation are released. The particle kinetic energy takes the form of heat and can be used for decomposing chemicals. In addition, the presence of charged and excited species renders the plasma environment highly reactive, which can catalyse homogeneous and heterogeneous chemical reactions. In plasma pyrolysis, the most likely compounds that form from carbonaceous matter are methane, carbon monoxide, hydrogen, carbon dioxide and water molecules. Reactions are illustrated in Table 2.

Plasma pyrolysis integrates the thermo-chemical properties of plasma with the pyrolysis process. Plasma pyrolysis uses extremely high temperatures of plasma-arc in an oxygen starved environment to completely decompose waste material into simple molecules. Hot plasmas are particularly appropriate for treatment of solid waste and can also be employed for destruction of toxic molecules by thermal decomposition. Unlike incinerators, segregation of chlorinated waste is not essential in this process. Another advantage of plasma pyrolysis is the reduction in volume of organic matter, which is more than 99%. Based on numerous advantages of plasma technology it is speculated that in the near future, plasma pyrolysis reactors will be widely accepted for toxic waste treatment². Unlike their smoke-belching, conventional counterparts, plasma pyrolysis facilities burn the waste without producing any harmful residuals.

In plasma pyrolysis the quantity of toxic residuals (dioxins and furans) is much below the accepted emission standards and it does not require segregation of hazardous waste. In addition, the pathogens are completely killed and there is a possibility to recover energy.

FCIPT plasma pyrolysis technology

A variety of high-temperature plasma torches have been developed at the Facilitation Centre for Industrial Plasma Technologies (FCIPT), Institute for Plasma Research for material processing. The plasma torches are reliable and rugged. Power sources and control instrumentation capable of extended operation in demanding environment have also been developed. The plasma-torch technology has been adapted for the development of an indigenous

Table 2. Molecular dissociation by plasma

Thermal cracking by plasma
Partial oxidation in the presence of water vapour
Reactions
$C + H_2O \Rightarrow CO + H_2$
$C + 2H_2O \Rightarrow CO_2 + 2H_2$
$C + CO_2 \Rightarrow 2CO$

plasma pyrolysis reactor for the safe disposal of medical waste in a collaborative project with Technology Information, Forecasting and Assessment Council, New Delhi.

The system consist of the following sub-systems: plasma torch, power supply, gas injection system, primary reaction chamber, secondary reaction chamber, quenching-system-cum-scrubber, induced draft fan and chimney. A schematic diagram of the plasma pyrolysis reactor developed is shown in Figure 1.

Plasma torch

The plasma torch consists of a water-cooled tungsten tip with an auxiliary copper anode surrounding it. The water-cooled anode cup is placed in front of the cathode. Both anode and cathode are surrounded by a magnetic field coil, which produces an axial magnetic field parallel to both the anode and cathode axes. The whole torch assembly is mounted on a flange of 100 mm diameter in a side port. The arc is initiated between the cathode and the auxiliary anode, and then transferred to the copper anode. The spectroscopic measurement suggests that the temperature near the cathode is around 20,000 K, while near the anode tip it is around 7000 K. The temperature is around 1500 K close to the waste. In addition, the hot flame rises and spreads out. The plasma-arc jet is shown in Figure 2.

Power supply

Fifty kW dc power supply used for plasma pyrolysis experiments has been developed indigenously. This power supply has open circuit voltage of 400 V, arc voltage of 125 V and maximum arc current of 400 amperes. It has a high voltage (3.5 kV) and high frequency (4 MHz) arrangement to strike the arc.

Gas-injection system

N₂ gas is injected through the torch and flow of gas is controlled using rotameters. There is an arrangement in the torch port to introduce steam or compressed air in the reaction zone of the primary chamber.

Process chamber

The process chamber is inclined as shown in Figure 1. It is made up of mild steel and has waste-feeding arrangement, mild-steel shell, glass-wool shielding, etc. The feeder has a double-door facility, where the inner door has a fish-mouth locking which avoids leakage of the gas. The door operates pneumatically. The outer door of the feeder has proper sealing to prevent gases from spreading in the working environment, while the inner door is opened for feeding the material.

Secondary chamber

While disposing contaminated hospital waste, one important requirement is that the gases, which come out from the primary chamber, have to pass through a temperature zone of 1050 ± 50°C in the secondary chamber. Hot gases produced in the primary chamber contain hydrocarbons, carbon monoxide and hydrogen in excess quantity. These gases are burnt in the secondary chamber with some excess quantity of air and they convert into CO₂ and H₂O. The secondary chamber is designed in such a way that the

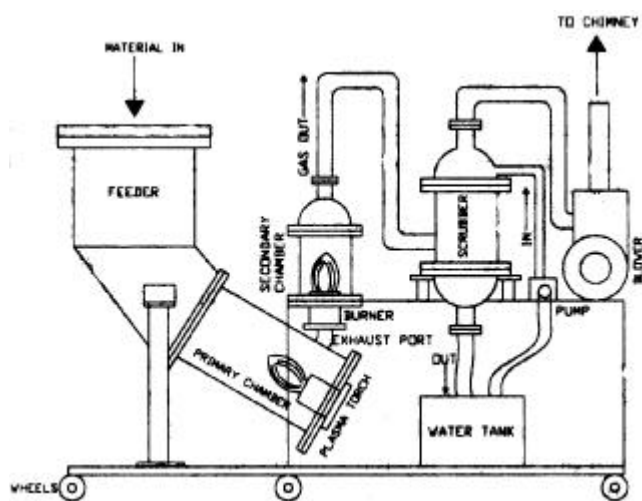


Figure 1. Schematic of plasma pyrolysis system.



Figure 2. Plasma torch producing high temperature plasma.

residence time of the gases is sufficient for combustion reactions to be completed.

Quenching-cum-scrubbing system

The quenching-cum-scrubbing system is made up of mild steel and has ceramic lining at the inner wall of the chamber. NaOH solution pH 12, at normal temperature is circulated with the help of a fountain in the chamber. Hot gases that pass through the scrubber are quenched to inhibit recombination reactions. The height of the scrubber is selected in such a way so that it maintains sufficient residence of the gases to reduce the temperature from 1000°C to ambient. Use of dilute NaOH will remove HCl from the residual gases.

Induced draft fan and chimney

Induced draft fan is used to take the residual gases at the chimney's height where these gases are released in the atmosphere. The fan also serves to create negative pressure in the primary chamber and to suck excess air into the secondary chamber for combustion reactions.

Description of pyrolysis process

An arc is produced between the two electrodes using dc power supply. A high voltage, high frequency generator is used to strike the plasma. The magnetic field rotates the arc root at the anode to reduce electrode wear. N₂ gas is employed to produce plasma. The required process temperature, approximately 900°C in the primary chamber, is attained rapidly.

The pyrolysed gases are burned in the presence of excess air in the secondary chamber. Combustion of the pyrolysed gases takes place and a long flame is observed. The gas samples are collected at the outlet of the second

dary chamber for analysis. After combustion, the hot gases are passed through a quencher-cum-scrubber, where the gases are quenched in alkaline water (12 pH) which brings down their temperature to 80°C or less. In case chlorinated waste is pyrolysed, HCl is one of the gaseous components produced that is scrubbed-off by the alkaline solution. The quenching restricts recombination reactions which otherwise produce toxic compounds. The residual gases are released with the help of an induced draft fan and chimney.

Destruction of *Bacillus stearothermophilus* and *Bacillus subtilis* bacteria grown on stainless-steel strips and exposed to the plasma environment in the primary chamber, has been demonstrated.

Results and discussion

This section describes the plasma pyrolysis process and the studies conducted on simulated hospital waste.

It has been observed that when the primary chamber is not preheated before feeding the waste, white smoke is released on pyrolysis of waste. The formation of white or non-black smoke is an indication of insufficient temperature in the reactor. This smoke is due to the evaporation or cracking of hydrocarbons to some extent, which get condensed to liquid aerosols, and with the solid particulate present, it appears non-black or white¹⁴. When the pyrolysis is done after the preheating, it results in greyish-black smoke which is an indication of pyrolysis reactions and generation of stable, less-complex hydrocarbon compounds that form as dark, minute particulates¹⁴.

Simulated hospital waste (cotton + plastic = 2 : 1) is fed in the primary chamber. High temperature in plasma processing leads to the decomposition of polymers that generates low molecular weight gases. The gases are collected from the outlet of the primary chamber for analysis, which is done by gas chromatography. During pyrolysis, formation of carbon soot has also been observed. The soot sample is analysed with Scanning Electron Microscope (SEM). Figure 3 shows SEM of soot. SEM study of the soot shows that carbon particles are present in agglomerated form. The cluster dimensions range from 300 to 600 nm.

Gas chromatography results of the plasma-pyrolysed, simulated medical waste (given in Table 3) reveal that

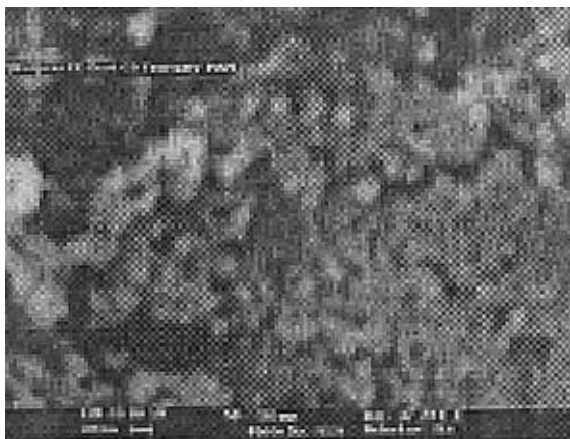
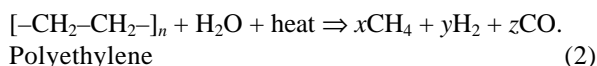
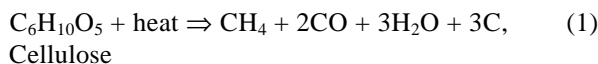


Figure 3. SEM of clusters of soot particles.

Table 3. Gases after pyrolysis

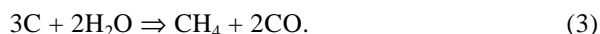
Gas	Quantity (%)
N ₂	45.0351
H ₂	22.6305
CO	26.6525
CH ₄	1.5073
CO ₂	4.20215
C ₂ -C ₅ (hydrocarbons: C ₂ H ₆ , C ₃ H ₈ , NC ₄ , IC ₅ , NC ₅)	0.4511

typical gaseous products formed are rich in hydrogen and carbon monoxide, with some lower hydrocarbons. As the total quantity of H₂ and CO in the gaseous mixture is more than 49% by volume, it thus provides a high temperature on burning. Possible reactions which take place during the pyrolysis of simulated hospital waste are described below¹⁴.



It is evident from Table 3 that the quantity of hydrocarbons formed in plasma pyrolysis is less, whereas the gaseous mixture contains CO and CO₂ in 26.65% and 4.20% respectively. These results are possibly due to the suction of air by induced draft fan through the minor leaks present in the primary chamber, which in turn reacts and produces CO and CO₂ in a large quantity. In the formation of CO and CO₂, the other source of oxygen is cotton (cellulose polymer).

It has been observed that the introduction of steam induces the combustion reactions which therefore restrict the soot formation up to some extent¹⁴.



The analysis of the gaseous sample taken after combustion (secondary chamber) shows that all toxic components of the gas mixture, i.e. CO, NO_x and SO₂ are present in low quantities. N₂ concentration is high because it is used as a plasmagen gas, and the air that is used to burn pyrolysed gases also contains 78% nitrogen. The source of SO₂ may be the rubber present as an impurity in the polymeric waste. Results are shown in Table 4. The following reactions occur in the secondary chamber.



A comparative study of concentrations of different gases which come out from the pyrolysis system and standards set by Central Pollution Control Board (CPCB), India is given in Table 5. The emitted gas concentrations are well within the limit of CPCB standards. It has been

Table 4. Gases after combustion

Gas	Quantity
N ₂	80–90%
CO ₂	10–15%
CO	40–85 ppm
NO _x	7–25 ppm
SO ₂	1–20 ppm
Lower hydrocarbons (C ₁ –C ₅)	10–95 ppm

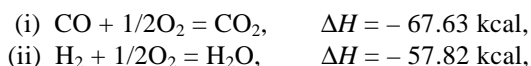
noticed that HCl forms when polyvinyl chloride or other chlorinated wastes are present in the waste. In such cases the alkaline pH solution that is used in the scrubber neutralizes the acid. Polyvinyl chloride plastic is not added in the waste for this study.

It has been observed that *B. subtilis* and *B. stearothermophilus* bacteria (spores) are destroyed completely when they are exposed to the reactive environment of plasma. It is attributed to higher temperature, which may cause degradation of DNA molecule of the cell. Rupture of DNA molecules may result in the killing of the bacteria.

Economic viability of plasma pyrolysis with energy recovery option

Plasma pyrolysis technology has been transferred to M/s Bhagwati Spherocast Ltd, Ahmedabad. A commercial system, which can treat waste at the rate of 25 kg/h, will be shortly demonstrated. It requires small space (~ 15 ft × 15 ft) for installation. On an average, 1 kW power is required to treat 1 kg waste⁶. Consumables in this process are mainly electricity, water and gas (N₂ or air). Economic viability of the process along with the energy recovery option has been explored. This is done for two types of waste: (i) medical and (ii) plastic waste, in our calculation.

Plasma pyrolysis of organic waste provides a large quantity of CO and H₂ gases as by-products. The electrical energy through the plasma is consumed in melting of plastics, bond dissociation (degradation) and in endothermic reactions. When the combustion of CO and H₂ is done, the following exothermic reactions take place with the release of energy in the form of heat and light.



Total energy released = (i) + (ii), $\Delta H = -125.45$ kcal.

This means that 125.45 kcal energy is released from the combustion of one g-mole of CO and one g-mole of H₂. It is evident from the literature that plasma incineration of 1 kg of polyethylene or any other organic waste requires around 860 kcal energy, which is equivalent to 1 kW electrical power^{6,7}.

Gas chromatograph results of the plasma-pyrolysed, simulated hospital waste (cotton + plastic in 2 : 1) reveal

Table 5. Emissions – a comparison with CPCB standards

Gas	CPCB concentration limit (ppm)	Concentration obtained at FCIPT (ppm)
CO	100	40–85
NO _x	450	7–25
SO ₂	50	1–20
Hydrocarbons	100	10–95
HCl	50	–

that typical gaseous products formed are rich in hydrogen and carbon monoxide with some lower hydrocarbons. As the total quantity of H₂ and CO in the gaseous mixture is more than 49% by volume (Table 3), it thus provides a high temperature on burning. If the residual gas has to be used to recover energy in the form of electricity, it should be free from corrosives/toxins and should have around 50% combustible gases. On the basis of these data, the plasma pyrolysis technology is evaluated for its economic viability. Calculations for energy recovery are described in Appendix 1.

It is clear from the calculations that if energy is recovered from the pyrolysed gases of medical waste, the destruction of approximately 600 kg waste per day for typically 50 kW system, is enough to break even. However, pyrolysis of plastic (polyethylene) provides more than 90% combustible gases; therefore, breaking even can be achieved by destroying approximately 300 kg polyethylene waste per day. Therefore, the energy recovery from the waste can make the technology economically viable.

Summary

Plasma pyrolysis process fulfils all the technical requirements to treat hazardous waste safely. It is easy to maintain the arc in an oxygen-free environment, or one can vary the plasmagen gas to alter the chemistry of the process. The plasma pyrolysis system can have instant start and shut down. It is possible to add features like interlocks and automation that make the system user-friendly. The plasma pyrolysis technology overcomes almost all the drawbacks of the existing waste-disposal technologies. It provides a complete solution for the safe disposal of medical waste. In addition, organic mass to gas conversion is more than 99% and it does not require segregation of chlorinated hydrocarbons. The gases obtained after the pyrolysis are rich in energy content and can be used to recover energy. After combustion, toxic gases are found in negligible quantity and fall within the limit of CPCB standards. High temperature and UV radiation present in the plasma kill bacteria completely.

Appendix 1: Energy recovery from waste

Capital cost for 50 kW system	: Rs 20 lakh
Operating cost (gas + electricity)	: Rs 13 per kg
Energy unit cost	: Rs 5 per 1 kWh

Based on the above data we have tried to estimate the break even at a disposal cost of Rs 15 per kg for two types of waste.

(a) Medical waste

From the available data we have selected medical waste which contain 60% cotton + 30% plastic + 10% fluid with 1 kg inorganics.

Variable cost	
Operating cost	: Rs 13 per kg
Effective operating cost after energy recovery*	: Rs 8 per kg
Margin	: Rs 7 per kg

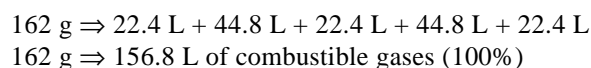
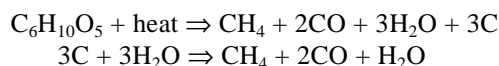
*1 kWh energy is generated from burning 1 kg of waste and in effect reduces the operational cost by Rs 5.00 (detailed calculations are shown below).

Fixed cost	
Interest on capital @ 18%	: Rs 1200 per day
Capital cost recovery (3 years)	: Rs 2222 per day
Maintenance (10%)	: Rs 667 per day
Total fixed cost	: Rs 4089 per day.

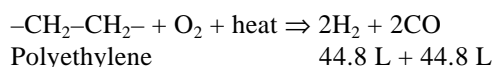
Break even can be achieved by burning approximately 600 kg medical waste per day.

Calculation for quantity of gas liberated

These calculations are based on the most probable reactions and the results obtained from gas analysis.



600 g cotton will produce ~ 580 L of combustible gases.



28 g polyethylene \Rightarrow ~ 89.6 L of combustible gases
 300 g polyethylene \Rightarrow ~ 960 L of combustible gases
 and 1000 g PE \Rightarrow 3200 L of combustible gases.

Combustion of 2200–2800 L (2.2–2.8 normal m³) of gas mixture (that contains ~ 50% combustible gases) generates 1 kWh energy, whereas if the gas mixture is composed of 100% combustible gases it requires 1100–1400 L (1.1–1.4 normal m³) gases for the production of 1 kWh energy¹⁵.

(b) Plastic waste

Complete pyrolysis of 1 kg polyethylene can produce approximately 3000 l of > 90% combustible gases.

Variable cost	
Revenue from energy recovery	: Rs 12.5 per kg
Operating cost	: Rs 13 per kg
Actual operating cost	: Rs 0.5 per kg
Margin	: Rs 14.5 per kg
Total fixed cost*	: Rs 4089 per day.

*2.5 kWh energy is generated from burning 1 kg of waste and in effect reduces the operational cost by Rs 12.50 (detailed calculations are shown above).

Break even can be achieved by burning approximately 300 kg plastic waste per day. It is clear from the calculations that energy recovery from plastic waste pyrolysis is more profitable than from medical waste.

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MEETINGS/SYMPOSIA/SEMINARS

Seminar on Bio-diversity, Biomass and Management

Date: 24–25 October 2002
Place: Thoothukudi

Broad subthemes identified for the seminar are: Developing technology for assessing the importance of pollution on species composition and their abundance in endangered marine and freshwater bioreserve; Status report on terrestrial pollution and its impact on plants and animals; State-of-art of the biodiversity studies carried out in the marine Park/Gulf of Mannar; Pollution status of inland water bodies and its impact on the species composition and productivity; Fish disease diagnosis and management.

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National Conference on Recent Trends in Plant Science Research

Date: 14–15 November 2002
Place: Pala

Topics include: Opportunities for R&D funding in India, Genetic engineering for crop improvement, Plant stress physiology, Intellectual property rights and plant science research, Recent advances in photosynthesis research, Need for conservation of plant biodiversity with special reference to medicinal plants, Plant biodiversity of Western Ghats – a treasure for future India, Impact of biotechnology on biodiversity, Bioinformatics in relation to genomics.

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