Plasma Pyrolysis Of Plastics Waste

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Abstract—Plasma Pyrolysis is a state-of-the-art technology which integrates the thermo-chemical properties of plasma with the pyrolysis process for safe disposal of solid wastes. It is an environment friendly technology and has over the past decade become more prominent technology because of realization of opportunities to generate valuable by-products by converting solid wastes. Intense heat of plasma (700 to 800 ^{0}C) enables it to dispose all types of wastes including municipal solid waste, biomedical waste and hazardous wastes. Plasma Pyrolysis of plastics wastes usually gives two product streams: a combustible gas having a calorific value in the range of 4-9 MJ/Nm^3 and a carbonaceous residue. Plastics waste is pyrolyzed at high temperature (800 to 1000 ^{0}C) into CO, H_2 and light hydrocarbon gases. This gaseous mixture called pyrolysis gas can be utilized for energy recovery via different applications. One such Plasma Pyrolysis technology has been developed at Facilitation Centre for Industrial Plasma Technologies, Institute for Plasma Research, Gndhinagar.

I. Plastics Waste Review

In any society of today's modern world, plastics provide a fundamental contribution to all main daily activities: agriculture; automobile industry; electricity and electronics; building materials; packing; and so on. As only a small amount of waste plastic is recycled and most plastics are not biodegradable, all these activities have led to the generation of an increased amount of plastic waste, particularly in more industrialized countries.

Since last six decades the Plastics industry has grown world wide with present consumption of more than 130 MMTPA [1]. In India, however, the consumption of major plastics is only 3% of global consumption i.e. about 4 million tons annually [1]. Despite this China has emerged as the largest consumer of plastics in Asia. As shown in Table I. below.

TABLE I.
DEMAND FOR POLYMERS INDIA VIS-A-VIS CHINA

Polymer growth & GDP (%)	**1990-2000**	**2000-2010**
India		
All polymers	14.3	14.0
PE/PP	16.3	15.1
GDP	6.0	~6.0
China		
All Polymers	18.5	8.8
PE/PP	19.5	9.4
GDP	10.3	~6.1

The growth of Plastics consumption in India is inevitable and desirable, because of multiple advantages this material provides. It helps improve quality of life. Preserves land, water and forest resources. Enable efficient use of non-renewable energy resources. Possess a more favourable cost-benefit ratio. It has a very versatile range of applications. And the demand of plastics will be further driven by factors like Population growth and urbanisation, Opening of rural markets, Effective media network.

"Currently, the country consumes around 4 million tonnes (mt) of plastic products which is expected to reach 12.5 mt by 2010. The country's plastic production, during the last year, has grown at a rate of 20 per cent," as said by Mr Kamal P Nanavaty, Chairman, National Executive Council, Plastindia Foundation and President, Cracker and Polymers Sector, Reliance Industries Ltd. [2].

It was estimated that India generates 5600 tones of plastic waste daily. Domestic consumption is 8 kg per head against the world average of 24 kg per head. The two main sources of scrap plastic in India as classified into two categories namely consumer waste and industrial waste. The consumer wastes include the wastes household waste, hospital waste and street waste. And industrial waste includes all the waste plastic from industries. Plastic waste demands the highest cost in the recycled market i.e.12-15 INR per kg. In the year 2002 around 2 million tones of plastic waste was collected countrywide.[3]

Technically the plastics waste constitutes two major category of plastics; (i) Thermoplastics and (ii) Thermoset plastics. Thermoplastics, constitutes 80% and thermoset constitutes approximately 20% of total post-consumer plastics waste generated in India. The Thermoplastics are recyclable plastics which include; Polyethylene Terephthalate (PET), Low Density Poly Ethylene (LDPE), Poly vinyl chloride (PVC), High Density Poly Ethylene (HDPE), Polypropylene(PP), Polystyrene (PS) etc. However, thermoset plastics contains alkyd, epoxy, ester, melamine formaldehyde, phenolic formaldehyde, silicon, urea formaldehyde, polyurethane, metalised and multilayer plastics etc.

II. Plastic Waste Management In India [4].

In India Recycling of plastics through environmentally sound manner involves four general types:

Primary recycling involves processing of a waste/scrap into a product with characteristics similar to those of original product.

Secondary recycling involves processing of waste/scrap plastics into materials that have characteristics different from those of original plastics product.

Tertiary recycling involves the production of basic chemicals and fuels from plastics waste/scrap as part of the municipal waste stream or as a segregated waste.

Quaternary recycling retrieves the energy content of waste/scrap plastics by burning / incineration. This process is not in use in India.

Polymer Coated Bitumen Road CPCB has undertaken a project in collaboration with Thiagarajar College of Engineering Madurai to evaluate the performance of polymer coated built roads laid during 2002-2006 in different cities. They observed that the coating of plastics over aggregate improves Impact, Los Angels Abrasion and Crushing Value with the increase in the percentage of plastics. The plastic tar roads have not developed any potholes

III. Plastics Waste Treatment Methods

Presently, the most common ways to deal with plastics waste, namely landfills and incineration, do not appear to be the most adequate solution since they are also associated with various problems related to the environment.

Landfilling of plastic waste, which is presently preferred much in India, is not a solution, essentially because it has been increasingly difficult to find suitable places for building technically adequate landfills. This is due to the resistance imposed by the nearby populations and since there is the danger of leaching and soil impregnation, with the subsequent contamination of underground waters. Furthermore, this process does not allow the recovery of the valuable organic content of plastic waste.

Incineration of plastic waste to produce heat may be a possibility, but its organic content would totally be destroyed and converted only into CO_2 and H_2O. In addition, depending on its nature, combustion may produce pollutants like light hydrocarbons, nitrous and sulphur oxides, dusts, dioxins and other toxins that have a highly negative impact on the environment.

IV. Non Incineration Techniques [5]

Plasma Pyrolysis comes under the category of non-incineration technologies or advanced pyrolysis techniques. Other known technologies are like Thermal Depolymerization, Reverse polymerization and other as shown in the Table no.II.

TABLE II.
NON INCINERATION TREATMENT TECHNOLOGIES FOR PLASTICS WASTE

Non-incineration Technologies	**Technology Vendors**
Reverse Polymerization	Environmental Waste International (Ajax, Ontario)
Thermal Depolymerization	Changing World Technologies (West Hempstead, NY)
Pyrolysis-Oxidation	Oxidation Technologies (Annapolis, MD
Plasma Pyrolysis	DayStar/Prometron (Tokyo, Japan)
Plasma Pyrolysis	Startech Environmental Corp. (Wilton, CT)
Plasma Pyrolysis	Integrated Environmental Systems (Richland, WA)
Plasma Pyrolysis	Plasma Pyrolysis Systems (Stuyvesant Falls, NY)

V. Plasma Introduction [6],[7]

The term *Plasma* was first introduced by Irving Langmuir (1928). At altitudes of approximately 100 km, the atmosphere no longer remains non-conducting due to ionization and formation of plasma by solar radiation. *Lightning* and the *aurora borealis* are the most common natural plasmas observed on Earth. Plasma is considered by many to be the '*Fourth State of Matter*', following the more familiar states of solid, liquid and gas. Addition of sufficient energy to a gas converts the gas into plasma. In other words, plasma is an ionized gas resulting from an electrical discharge, for instance. Plasma can be distinguished into two main groups of laboratory plasmas, i.e. the high temperature or *fusion plasmas* and the so called low temperature plasmas or *gas discharges*. A typical classification of different kinds of plasmas is given in Table III.

On Earth almost everything assumes one of the three solid, liquid or gas states, so the plasma (a ionized gas, composed by charged particles) comes after in the conventional order. Universally the fact is different 99% of total matter in universe is in the form of plasma. In the outer space, plasma is the most common state that matter assumes (think about stars!).

Plasma chemistry is clearly the chemistry organized in or with plasma. Thus, a plasma source, which in most laboratory conditions is a gas discharge, represents the physical and engineering basis of the plasma chemistry.

VI. Thermal Plasma Generators (Torches)[8]

The workhorse of plasma-based waste destruction technology is the plasma torch. The driver for the development of plasma torches was the space race in the 1960s. 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. DC and AC

Current, Radio Frequency and microwave power sources can be used to produce the arc.

The arc plasma generators can be divided into non-transferred arc torch and transferred arc torch. In a non-transferred arc torch, the two electrodes do not participate in the processing and have the sole function of plasma generation. For waste treatment systems non-transferred arc torches are preferred. In a transferred arc reactor, the substance to be processed is placed in an electrically grounded metallic vessel and acts as the anode; hence the reacting material should be an electrically conductive material. Transferred arc torches have been used widely in metallurgical processing

TABLE III.
CLASSIFICATION OF PLASMAS

Plasma	State	Example
High temperature plasma (Equilibrium plasma)	Te = Ti = Th, Tp = 10^6 K–10^8 K ne $\geq 10^{20}$ m^{-3}	Laser fusion plasma
Low temperature plasma Thermal plasma (Quasi-equilibrium plasma)	Te ≈ Ti ≈ Th, Tp = (2 X 10^3 K) –(3 X 10^4 K) ne $\geq 10^{20}$ m^{-3}	Arc plasma; Atmospheric radio frequency discharge
Non-thermal plasma (Non-equilibrium plasma)	Te>>Th ≈ (3 X 10^2K) – (4X 10^2 K) ne ≈ 10^{10} m^{-3}	Corona discharge

Te = electron temperature; Ti = ion temperature; Th = Neutral temperature; Tp = Plasma temperature; ne = Electron density.

VII. PLASMA PYROLYSIS SYSTEM

Thermal plasma pyrolysis is generally used in case of carbonaceous wastes from wherein some resource recovery is possible. Plasma pyrolysis is commonly used for organic wastes rich in carbon and Hydrogen. 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. 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%.

The Plasma Pyrolysis and energy recovery system is as shown in figure 1 developed at Facilitation Center For Industrial Plasma Technologies, Gandhinagar.

VIII. FCIPT PLASMA PYROLYSIS SYSTEM

The system consist of the following sub-systems: plasma torch, power supply, gas injection system, primary reaction chamber, Venturi scrubber, Water Tank, Packed bed scrubber, Filter, Condenser, Bag filter, ID Fan, Chimney, Buffer tank, Generator Set.

Plasma torch: The plasma torch consists of a two cathodes and one anode. Electrodes are made up of graphite. Cathodes are placed with their tip in front of each other while anode with its tip directed at right angel the tips of cathodes at the center.

Primary 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.

Venturi Scrubber: Where the pyrolysis gas is quenched to 50 to 60 ^{0}C through forced water stream. It is provided to quench the pyrolysis gas as fast as possible to avoid recombination reactions and for retention of soot particles formed. In case of plastics wastes (polymer source) soot particles formed will be much less as comparable to cellulose sources. But the most important use is to recover monomer from the polymer like ethylene from polyethylene, propylene from polypropylene etc. by reducing the further degradation reactions via sudden temperature fall.

Scrubbing: Provided for soot particle removal pyrolysis gas cleaning. It is provided with the packing of pebbles or ceramic balls.

Filter: Simple column with the packing of wooden logs or pieces with rough surface for pyrolysis gas cleaning.

Condensor: Cause of scrubbing the moisture content of the pyrolysis gas get increased. This high moisture content will result in energy loss for heating up of pyrolysis gas in the generator set. Hence a condenser is installed to remove excess moisture from the pyrolysis gas. Chilled water is passed towards the tube side and condensed water films are formed on its outer surface.

Bag Filter: Provided for removal of soot particles.

Buffer Tank: : Cool and clean pyrolysis gas are taken to buffer tank having Non returnable valve (NRV) which keeps the flow in forward direction. Buffer tank is provided to store the pyrolysis gas to ensure that no fluctuations in the gas feed rate to the generator set takes place. This ensures a constant output from the generator set.

Generator Set: The generator set used is an Internal Combustion (IC) engine. The clean and cool pyrolysis

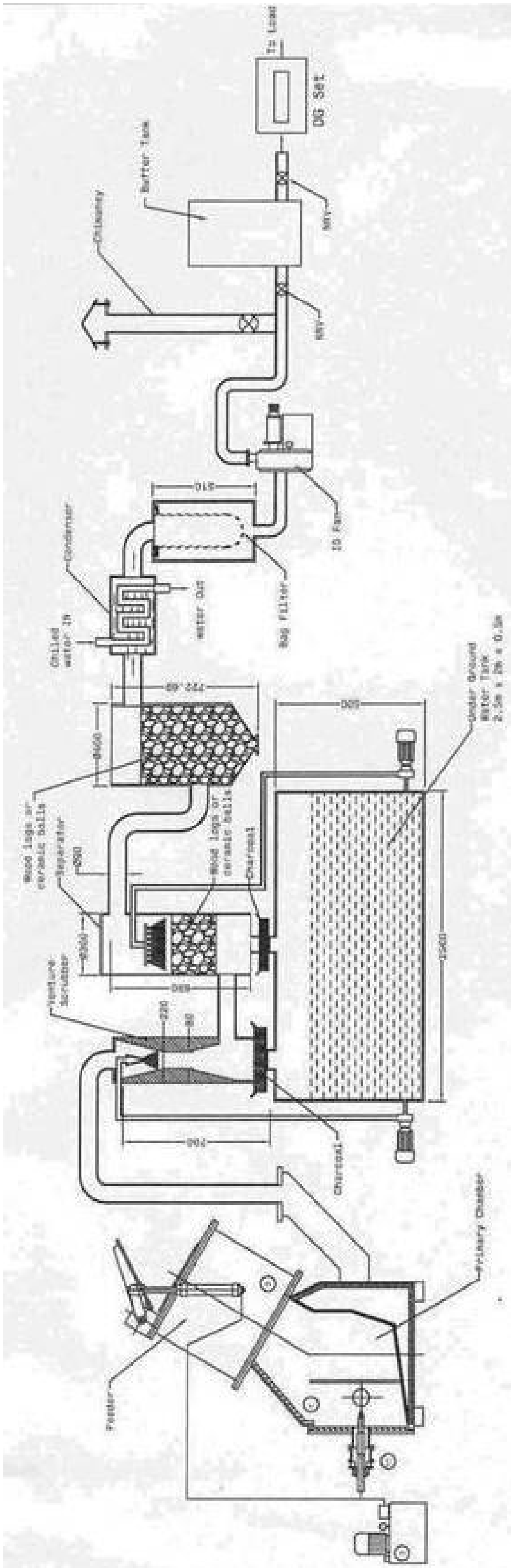

Figure 1. Plasma Pyrolysis Waste Treatment and Energy Recovery Systen Developed at FCIPT, Gandhinagar.

gas is combusted into the IC engine to run it at 1500 rpm. The IC engine is coupled with an alternator to generate electric power at 50 Hz.

IX. Plasma Pyrolysis of Polyethylene Reactions

Plasma Pyrolysis is a destructive decomposition process . High temperature is produced by plasma torch that converts electrical energy into heat energy in oxygen starved environment.

Pyrolysis reactions:

$[–CH_2–CH_2–]_n + H_2O + heat \rightarrow xCH_4 + yH_2 + zCO$.(1)
Polyethylene
Monomer

Also minor soot formation has been detected, the reason being not clear so far. These soot undergoes following reaction

$3C + 2H_2O \rightarrow 2CO + CH_4$………………………… (2)

Combustion reactions:

$2C + 2O_2 \rightarrow 2CO_2 + 2 \times (94.05)$ kcal…………… (3)

$2H_2 + 2O_2 \rightarrow 2H_2O + 2 \times (57.82)$ kcal…………(4)

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

Table III.
Product Distribution With Quench Process

Material: Polyethylene With quench process using Argon as plasma gas	
Product	Distribution (vol.% Ar free basis)
Propylene	53.39
Ethylene	22.24
Methane	5.62
Acetylene	5.70
1,3-Butadiene	3.65
Solid conversion	~50

X. Concluding Remarks

Thermal plasma pyrolysis is in the forefront of modern waste treatment. There is great potential for development of thermal plasma pyrolysis technologies applicable to waste management with energy and material recovery. The rapidly increasing pressure of environmental protection and energy and resources conservation may hasten development and industrial implementation of the technology in the near future.

XI. Acknowledgement

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