Indo American Journal of Multidisciplinary Research and Review (IAJMRR)
ISSN: 2581 - 6292 / Impact Factor: 6.885 / Website: www.iajmrr.com

MUNICIPAL SOLID WASTE TREATMENT BY PLASMA TECHNOLOGIES

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Cite This Article: R. Krishna Moorthy, Dr. S. P. Vendan & Dr. S. Balachandran, "Municipal Solid Waste Treatment by Plasma Technologies", Indo American Journal of Multidisciplinary Research and Review, Volume 4, Issue 2, Page Number 14-25, 2020.

Abstract:

This paper deals with the uses plasma technology to treat municipal solid waste. The analysis indicates that gasification is a technically viable option for the solid waste conversion, including residual waste from municipal solid waste. It is viable to meet existing emission limits and can have a remarkable effect on reduction of landfill. Disposal of domestic and industrial waste is always a problem and it is being attempted all over the world to solve this at a local level also ensuring various compliances applicable for the particular waste. Safe disposal of this different type of waste like MSW and TSW is the central aim of this paper. Solid waste disposal is always attempted in many ways and here plasma technology is being used for this activity. Plasma generates a high temp arc which transfers heat to the items where it is passed or directed. Since it is thermal transfer process it is experimented to find the feasibility the recovering thermal energy from exhaust gases and it is also analyzed to utilize exhaust gas components for utilization.

Key Words: Plasma Technology, Municipal Solid Waste, Textile Sludge & Syngas Production

1. Introduction:

Solid Waste management (SWM) is very acute and intricate problem in developing country economies like India. Progressing states have meager budget for waste management and major portion of which goes to collection and transportation rather than its treatment .Over a period of time waste management become a serious problem in developing countries. Mountains of hazardous waste have been created on the outskirts of mega cities. These mountains create serious threats to both flora and fauna. Various methods like land filling, incineration and composting have been used for waste management, but none of them fully satisfy the growing need of waste management in major cities.

In this work we have compared various methods of Waste management and suggested comparatively better method of plasma arc gasification, in which pyrolysis of solid waste takes place at very high temperature thus ensuring syngas as the output of gasifier. The method not only treats all types of waste, but also produces many useful byproducts and electricity. The set-up ensures closed loop cycle thereby reducing pollution and suits the needs of developing countries and can be potential SWM method in the coming future.

Presently about 1260 million tones of waste are generated annually in India. Per day approximately 700g per capita of waste is generated. Major portion of SWM budget is being utilized in collection and transportation of the waste. For example in India Urban bodies spent about 60-70 % in collection of waste and remaining 20-30 % is spent on its transportation.

Landfill sites and incineration continue to be the primary methods used to dispose wastes with significant negative impact on the environment. Landfill releases methane which is 21 times more dangerous as a greenhouse gas than carbon dioxide. Incineration is often pushed as an alternative to land filling. However, it is a known fact that incinerator ashes are contaminated with heavy metals, unburned chemicals and new chemicals formed during the burning process. These ashes are then buried in landfill or dumped in the environment. Sustainable and successful treatment of MSW should be safe, effective, and environmentally friendly. Application of plasma gasification in waste to energy is one of the novel applications that were introduced several decades ago. In plasma arc gasifying vessel, the organic waste materials are gasified to generate a syngas which can be used to produce energy.

Proper disposal of MSW is a necessity to minimize environmental health impacts and degradation of land resources. In developing countries, MSW is commonly disposed of by transporting and discharging in open dumps, which are environmentally unsafe. Systematic disposal methods are composting, land filling and incineration. Looking at the most common disposal methods in the study countries indicate the share of open dumping to be 60% in India, 85% in Sri Lanka, 65% in Thailand and 50% in China (Figure 1.1). The so-called landfill is mostly covering refuse in the dumpsite by soil neither with proper technical input nor with treatment of the emerging emissions to water, air and soil.

Solid waste is one of the main by-products of human society, but at the same time, it is also a potential energy source which has attracted more and more attention over the years. The waste-to- energy conception has become one of the most popular topics in energy field.

1.1 Wastes Classification:

Wastes are usually classified according to the form in which they appear and according to the hazardous material content.

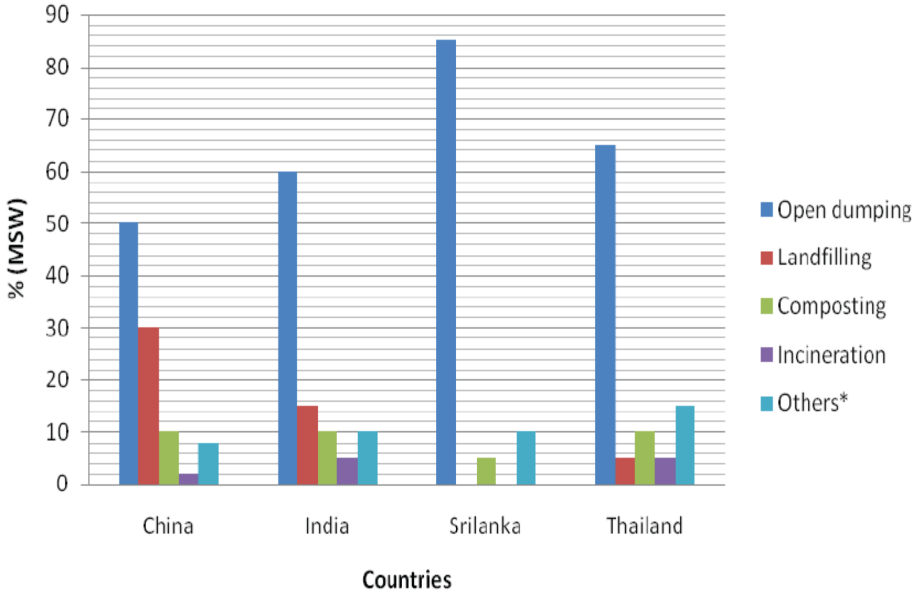

Figure 1.1: MSW disposal methods practiced in study countries

Following is a frequently used list of different waste materials:

- Hazardous liquids and gases, chlorinated fluorocarbons (CFCs) and various widely used solvents. Most of these fluids, with the exception of CFCs, have relatively high heating values; however, their incineration can lead to the formation of other hazardous products because of the presence of halogens.

Figure 1.2: Waste types

- Municipal solid waste (MSW), the largest waste stream, usually with low levels of contaminants, traditionally deposed of in landfills. However, limitations on landfill use have necessitated use of volume reduction methods.
- Incineration is widely used because of the heating value of the waste.
- Hospital solid waste (HSW), with a wide range of contaminated material. The high heating values favour incineration.
- Incinerator residues, i.e. bottom ash and fly ash, frequently containing heavy metals as contaminants.
- Sewage sludge waste (SSW) and other sludge wastes, with a range of organic contaminants, and high moisture content.

- Manufacturing wastes that lend themselves to materials recovery, such as electric arc furnace (EAF) dusts and aluminum dross.
- Recovery of valuable materials from waste, e.g. platinum from discarded exhaust catalysts.

1.2 Composition of Municipal Solid Waste:

The major components of solid wastes include garbage, rubbish, incombustible ashes, street wastes as well as special wastes. Garbage mainly includes all types of biodegradable organic wastes collected from kitchens, hotels, restaurants etc. The major portion of garbage comprises of food articles, vegetable/fruit peelings etc. Rubbish includes either combustible (paper, plastic, textiles etc.) or incombustible (broken glass, crockery, metal, masonry etc.) materials. The incombustible ash mainly consists of ashes from industrial and household hearths.

Street sweeping mostly includes fine dust, silt and sand along with the leaves, papers/wrappers etc. In addition to above four usual components, solid waste also includes special wastes such as, construction debris, abandoned appliances, automobiles and electronic wastes. In rural areas, however, the cattle dung and crop wastes comprise the dominating portion of solid waste

For the purpose of selecting the optimal treatment process, a further classification can be made according to the waste composition:

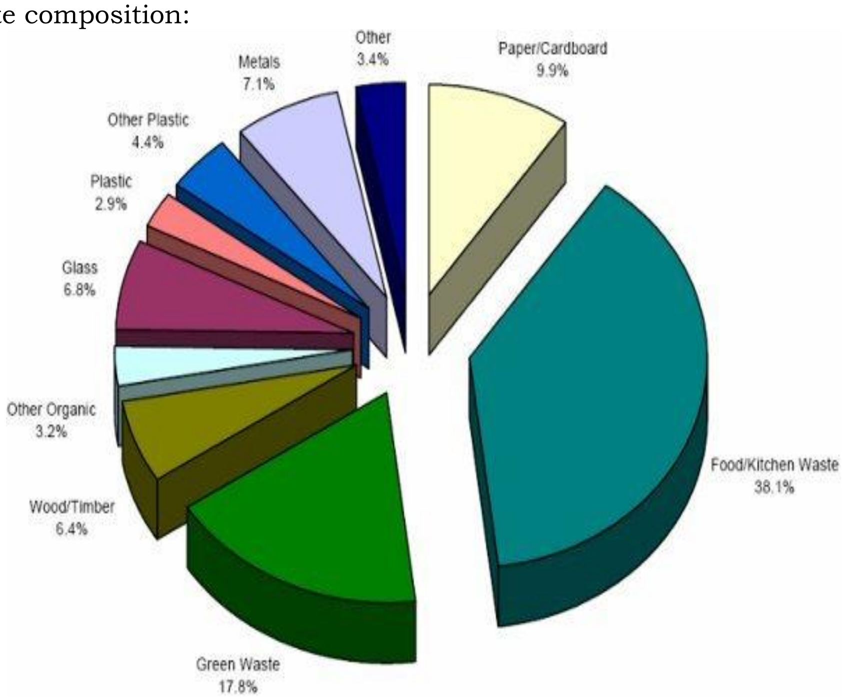

Figure 1.3: Composition of MSW

- Wastes with high concentration of organic materials with high heating values; recovery of this heating value in the form of synthesis gas (syn-gas) using a plasma process is an attractive alternative to complete combustion and steam generation.
- Wastes with high concentration of halogen, e.g. including most of the plastic materials; these require higher temperature treatment and quenching, and it is more difficult to obtain a saleable co-product.
- Inorganic solid materials which can be treated for reclamation of valuable components or can be reduced in volume through melting or can be oxidized and immobilized in a non-leaching slag.

For contaminated solid wastes, decontamination is desired in conjunction with volume reduction and immobilization of inorganic contaminants. The high heat fluxes available in transferred arc reactors provide advantages for melting of solids, and most solid waste treatment approaches use some form of transferred arc reactor

Plasma waste treatment is one of the technologies seen as a effective method because of the increasing problems with waste disposal and because of the realization of opportunities to generate valuable co- products.

1.3 Plasma Technology Concept and Use:

Plasma Gasification is one of the most recent and efficient method for SWM. It involves gasification of solid waste using plasma arc treating the exhaust gases and employing syngas to run "Integrated Gas Combined Cycle" to produce electricity, using the vitreous slag as a by-product in real estate industries and harnessing toxic gasses like sulphur for laboratory and pharmaceutical. Thus ensuring zero emission in the environment and using all the constituents including calorific value of the solid waste for the benefit of mankind.

Plasma is a superheated column of electrically conductive gas. In nature, plasma is found in lightning and on the surface of the sun. Plasma torches burn at temperatures approaching 10,000°F and can reliably destroy any materials found here on earth with the exception of nuclear waste, since radioactive isotopes are not broken down by heat.

Plasma is considered to be the fourth state of matter, consisting of a mixture of electrons, ions and neutral particles, although overall it is electrically neutral. The degree of ionization of a plasma is the proportion of atoms that have lost (or gained) electrons and, in the case of thermal plasmas of interest for this review, this is controlled mostly by temperature.

Plasma technology involves the creation of a sustained electrical arc by the passage of electric current through a gas in a process referred to as electrical breakdown. Because of the electrical resistivity across the system, significant heat is generated, which strips away electrons from the gas molecules resulting in an ionized gas stream, or plasma. At 2000 °C gas molecules dissociate into the atomic state and when the temperature is raised to 3000°C, gas molecules lose electrons and become ionized. In this state, gas has a liquid-like viscosity at atmospheric pressure and the free electric charges confer relatively high electrical conductivities that can approach those of metals.

The thermal plasma process ensures gasification of the carbon-containing materials in the waste to produce synthesis gas (syngas) composed primarily of carbon monoxide and hydrogen, which is used to produce energy through reciprocating engine generators - gas turbines and steam boilers in integrated plasma gasification combine circle (IPGCC). Inorganic components get converted to glassy slag safe for use as a construction aggregate.

Thermal plasmas have numerous advantages including: high temperature; high intensity, non-ionizing radiation and high energy density. The heat source is also directional with sharp interfaces and steep thermal gradients that can be controlled independently of chemistry. Whereas an upper temperature limit of 2000˚C can be achieved by burning fossil fuels, electrically generated thermal plasmas can reach temperatures of 20,000˚ C or more.

Thermal plasma reactors offer a range of other advantages including:

- High throughput with compact reactor geometry;
- High quench rates (>106 K/s) allowing specific gas and solid material compositions to be obtained;
- Low gas flow rates (except for non-transferred plasma devices) compared to the combustion of fossil fuels, thereby reducing the requirements for off-gas treatment.

Artificial Plasma is created by passing a gas between electrodes with large differences in electrical potential and by exposing the gas to high temperatures, as in the case of arc welding or graphite electrode torches.

1.4 Plasma Advantages and Disadvantages:

A possible disadvantage, especially from an economic perspective, is the use of electrical power as the energy source .However; a complete comparative cost evaluation often demonstrates the economic viability of plasma-based technologies.

US Environmental Protection Agency has declared that "One technology which potentially can use various types of waste, produce electricity and hydrogen without emitting dioxin, furan and mercury, is plasma arc technology. Municipalities can install a plasma arc facility which will eliminate land filling."

2. Materials Sample:

2.1 Municipal Solid Waste Sample:

Municipal solid waste is collected from Vellalore dumping yard in Vellalore, Coimbatore District (Fig 2.1). Necessary permission to collect the Municipal solid waste is obtained from the Coimbatore Corporation.

Municipal solid waste is collected from the yard where final treated waste is dumped in open land.

The sample is collected carefully from the yard where it is stored. It is stored in PVC bags before testing. The samples are later used for plasma treatment.

Fig. 2.1: Vellalore dumping yard, Coimbatore District

2.2 Textile Sludge Waste Sample:

Textile sludge after treatment from central treatment is collected from central effluent plant in Arulpuram, Palladam. Necessary permission to collect the textile sludge is obtained from the TN Pollution Control Board and it the officials of Central Effluent Treatment plant at Arulpuram.

Textile sludge is collected from the yard where final treated waste is stored in open land. It appears white in color in powder form with moisture. (Ref Figure 2.2)

The sample is collected carefully from the yard where it is stored. It is stored in PVC bags before testing. The samples are later used for plasma treatment

Figure 2.2: TSW collected from Central Effluent Treatment Plant

3. Feed Preparation:

The sample is preheated in oven to remove moisture and it is kept in ball shaped containers for better binding PVC binders are also added. The sample if kept dry powder form it may not able to remain in the chamber due to the speed of arc.

Electrical power input controls are there to vary the supply voltage and current. Both the cathode and anode are of graphite and the water cooling arrangement is available to continuously circulate the water while in operation Base holding the sludge is graphite crucible and the top

Figure 3.1: MSW sample taken for plasma treatment

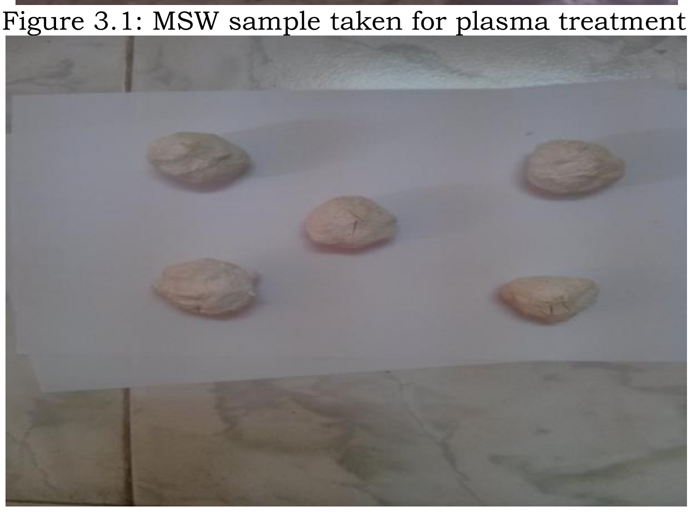

Figure 3.2: Textile Sludge kept ready for plasma treatment

4. Experimental Set Up:

Plasma arc torches utilize a combination of these techniques. The extremely intense energy produced by the plasma torch is powerful enough to disintegrate the MSW into its component elements. The systems are shown in Figs 4.1.,

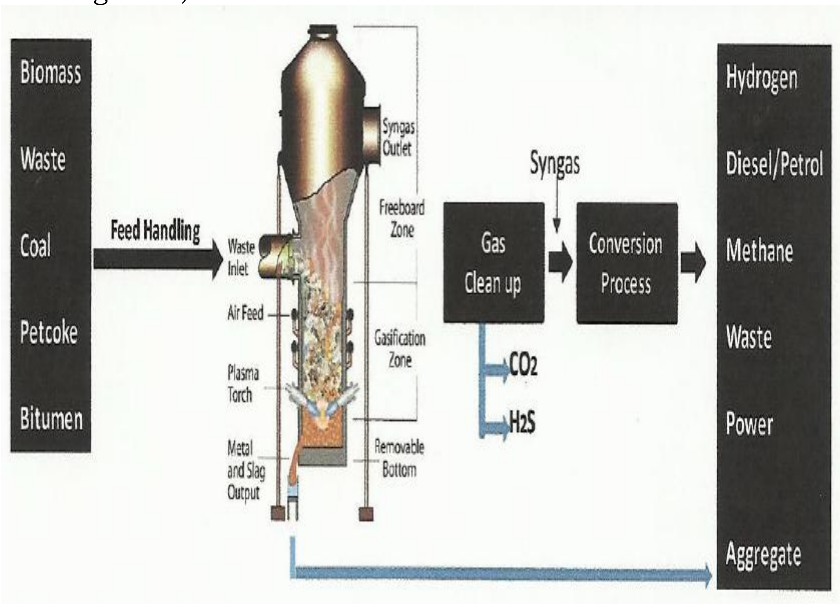

Figure 4.1: Plasma Conversion process

The various sub-systems include:

- Waste handling and preparation system.
- The plasma furnace or cupola with plasma torch system.
- The gas cooling and cleaning system to remove pollutants.
- Various energy conversion processes.
- Wide range of valuable products

First is characterized by high-energy density and equality of temperature. Second is the having lower energy density and large difference between the temperatures of the electrons and the heavier particles. It is possible to maintain discharge even at room temperatures. DC non transferred plasma torches fall in this category and it is more commonly used for plasma applications.

Plasma torch used in this study is represented in the fig below.

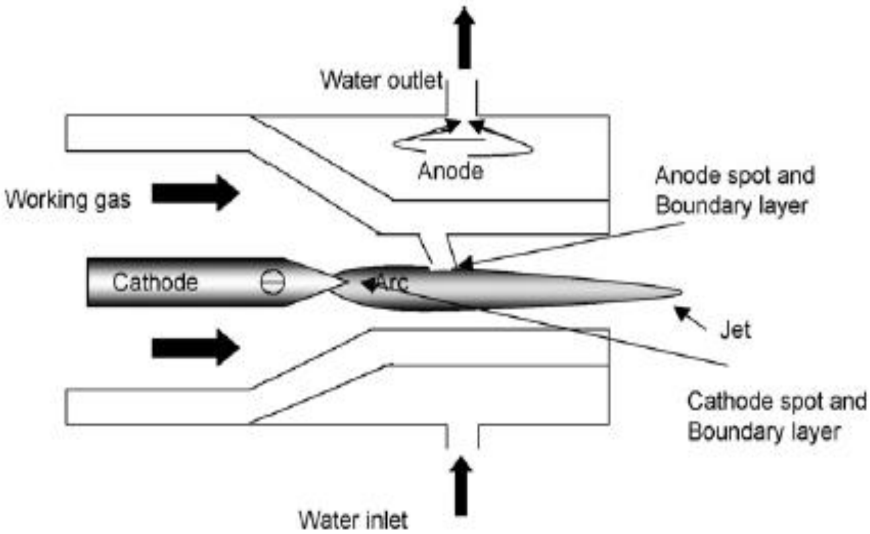

Figure 4.2: Schematic diagram of a DC non transferred torch

The plasma torch is having water cooled electrodes. The plasma exiting the water-cooled plasma torch has peak temperatures of 10 000–14 000K depending on the torch power level, the plasma gas and the torch design. However, since the plasma is decaying outside the torch, the material to be treated is usually not exposed to these high temperatures, and 'average' values are used for temperature and velocity of the plasma flow.

A non-transferred plasma torch with a tungsten cathode and copper anode was used and to evaluate the reduction in volume and removal of hazardous elements in fly ash and sludge. Leaching test on the vitrified slag showed that metal, such as copper, zinc and lead and other heavy metals that metals leached below the regulatory limits.

Figure 4.3: Closed chamber set up

These experimental set up is available in thin films laboratory, Bharathiar University, Coimbatore. Necessary permission obtained to conduct trials.

Top portion of closed chamber is a mild steel sheet and the dome near he top is made of stainless steel. Dome is used for deposition or nano recovery studies. Both these parts are fabricated to conduct the trials in closed chamber.

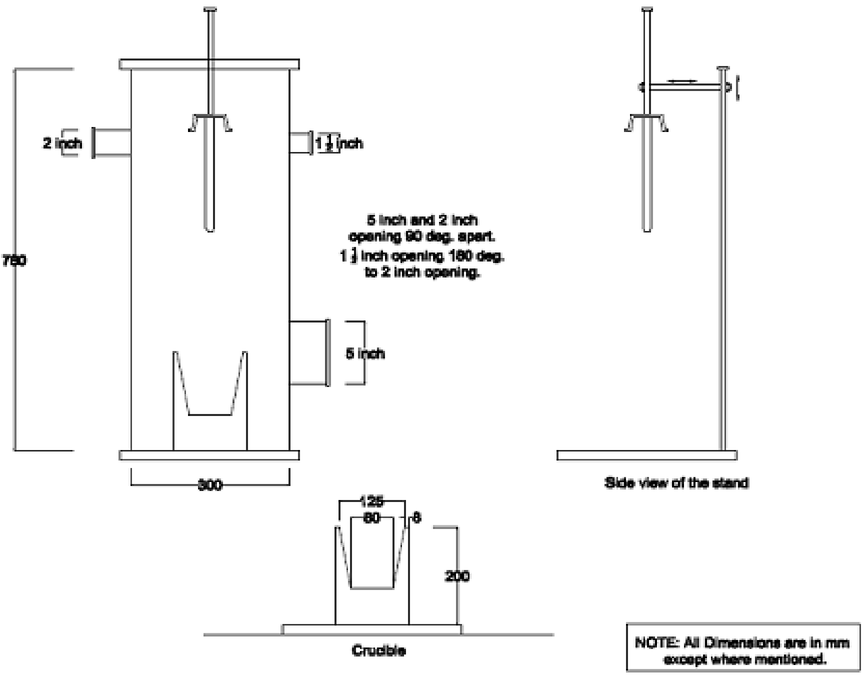

Figure 4.4: Closed chamber line sketch

4.1 Gas Collection:

Here evacuated bladders are used to collect the gas samples. It is fitted with quarter turn ball valves at the top with adopters. The gas after going inside can be stored there without leaking by operating the valve.

Figure 4.5: Bladder gas collection arrangement

All the openings are closed flanges and bolted (Ref Figure 4.6). To ensure leak proof all the flanges are with grooves and it is fitted with gaskets. Each flange is ensured that the appropriate gasket is kept in the groove before bolting. The gas collection is made in one flange where it is having a bleed opening with screwed ends. Through a screwed end adaptor it is fitted to copper tube since the gas coming out is well above 70°C.

Copper tube length is around one meter to give the gas sufficient run so that it gets cooled before exit. It passed through a glass u tube with cotton for filtering the dust particles and silica jel to remove moisture present in the exit gas. Because the presence of dust particles and moisture will damage the gas analyzer.

Figure 4.7: Electrical controls for setting the power variation

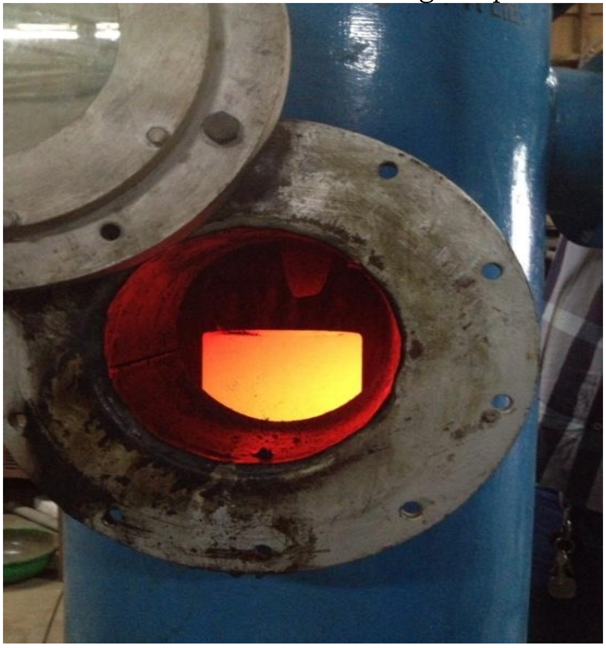

Figure 4.6: Closed chamber gas collection arrangement

Electrical controls are kept in the table (Ref Figure 4.7) near the chambers. It has electronic controllers to change the voltage and supply current. The variation of supply power is possible with this arrangement and it is possible to conduct test at various supply conditions and the results are recorded to further evaluate the results

The experiment is carried out in two ways. The sample is weighed and subjected to plasma arc exposure for different input supply conditions .Both duration and input feed is varied. Final slag output weight is measured after cooling. In each case the argon gas consumption is noted. In the next type input power and mass feed is kept constant and the slag output weight is measured for each trial. Conducted the above experiments in 20 kVA test facility in Bharathiar University thin films laboratory.

In this test input power & mass feed weight are kept constant. The gas sample are collected in evacuated bladders and composition is analyzed in gas chromatography.

4.2 Volume Reduction of Solid Waste:

Depending on its composition, Plasma arc reduces the volume of solid wastes to be disposed of by an average of 95%. The weight of the solid wastes to be dealt with is reduced by 90 – 95%. This has both environmental and economic advantages since there is less demand for final disposal to landfill, as well as reduced costs and environmental burdens due to transport, if a distant landfill is used. Volume reduction is finally measured by weight % reduction after treatment. Here the weight% reduction after treatment of Municipal solid waste and textile sludge is studied in various trails.

5. Analysis:

The pollutant features of municipal solid wastes differ widely among various Organic substances such as E-waste, food waste, plastics, wooden waste, dyes, starches and detergents in effluent undergo chemical and biological changes which consume dissolved oxygen from the receiving stream and destroy aquatic life. Such organics should be removed to prevent septic conditions and avoid rendering the stream water unsuitable for municipal, industrial, agricultural and residential use.

The input is found to contain Hydrocarbons, sulphur, others metals and it dissociates into Methane, Carbon mono oxide and carbon di oxide due to plasma treatment. The plasma treated slag is also subjected to XRD test and it contains as a major content as per the theory

5.1 Municipal solid waste Sample:

Municipal solid waste has a variable composition and normally contains high organic matter, C, S, N, P, K and micronutrients contents. Additionally, heavy metals and pathogen microorganisms may be presented

The MSW sample collected from common collecting station is subjected to ultimate analytical testing.

Composition	Concentration (%, dry basis)
C	45.06
H_2	6.98
O_2	42.27
N_2	2.90
S	0.27

Table 5.1: Contents of Ultimate Analytical Report of MSW sample

5.2. Textile Sludge Sample:

Textile sludge has a variable composition and normally contains high organic matter, N, P, K, Calcium and micronutrients contents. Additionally, dyes, heavy metals and pathogen microorganisms may be presented

The sample collected from common effluent plant is subjected to ultimate analytical testing.

Composition	Concentration (%, dry basis)
C	52.54
H_2	5.69
O_2	40.7
N_2	0.44
S	0.21

Table 5.2: Contents of Ultimate Analytical Report of TSW sample

The Hazardous contents are reduced to levels below the Pollution control norms. Calcium being the major content it is the first attempted to find a way to convert or reuse in a useful way. The feed sample is subjected to xray difraction test.

Artificial Plasma may be created by passing a gas between objects with large differences in electrical potential, as in the case of lightning, or by exposing gases to high temperatures, as in the case of arc welding or graphite electrode torches. Plasma arc torches utilize a combination of these techniques.

The extremely intense energy produced by the torch is powerful enough to disintegrate the MSW into its component elements.

Syngas is a mixture of hydrogen and carbon monoxide and it can be converted into fuels such as hydrogen, natural gas or ethanol.

The Syngas so generated is fed into a heat recovery steam generator (HRSG) which generates steam. This steam is used to drive steam turbine which in turn produces electricity. The cooled gas is also used to drive a second turbine to generate additional electricity – The integrated gasification combine circle (IGCC) thus produce adequate electricity, part of which is used for the plant's load and the rest of the power generated is sold to the utility grid.

Essentially the inorganic materials such as silica, soil, concrete, glass, gravel, including metals in the waste are vitrified and flow out the bottom of the reactor. There are no tars, furans or ashes enough to pollute the environment.

Current is maintained at a 300 amp and voltage is kept constant at 60 volts. Input weight is not changed. Gas samples are collected

Output slag taken for detailed XRD tests and match phase results.

Figure 5.1: Output slag of MSW after cooling

Figure 5.2: Output slag of TSW after cooling

Gas sample is taken for further analysis by gas chromatography. It shows existence of the significant % of syn gas ($CO+H_2$) at exhaust temperatures. %CO increase with duration of the test indicates that it takes some time to attain stable or almost steady state.

Figure 5.3: Gas chromatography arrangement

The subsequent reaction produces syngas and byproducts consisting of glass-like substances used as raw materials for construction, and also re-useable metals.

$$2C+O_2 \rightarrow 2CO$$
$$C+CO_2 \rightarrow 2CO$$
$$C+H_2O \rightarrow CO + H_2$$

After burning of MSW and TSW to collect exhaust gas and it undergo to gas chromatography to analysis the composition of exhaust gas. The result are given the following table

Composition	Concentration (%)
H_2	22.356
CO	18.672
CH_4	2.933

CO_2	15.423
C_2H_2	1.158
C_2H_4	0.245

Table 5.3: Exhaust gas Composition of MSW sample

Composition	Concentration (%)
H_2	2.598
CO	17.611
CH_4	2.094
CO_2	8.729

Table 5.4: Exhaust gas Composition of TSW sample

6. Results and Discussion:

Finally to compare the composition of MSW and TSW before the burning based on the ultimate analysis result

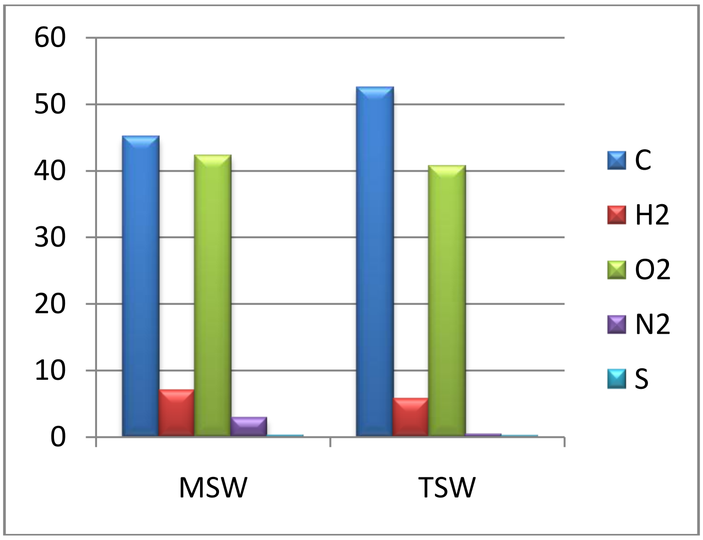

Figure 5.2: Comparison of composition of MSW and TSW (before burning)

Then MSW and TSW are processed by Plasma technology to produce exhaust gas .so finally to compare the exhaust gas Composition of MSW and TSW based on the gas chromatography analysis result

Table 6.2: Comparison of Exhaust gas Composition of MSW and TSW sample

First step in any solid waste disposal is to start with volume reduction. Here the weight reduction which will result in volume reduction at various conditions.

S.No	Type of waste	Initial weight (gms)	Final weight (gms)	Weight reduction %
1	MSW	240	22	90.84
2	TSW	250	45	82

Table 6.1: % of weight reduction of MSW and TSW sample

7. Conclusion:

For any solid waste disposal, the volume or mass reduction is the first step and the values obtained prove that plasma can give same or even better result than the conventional methods is this front.

MSW is reduced as Syngas (CO, CH_4) and carbon dioxide is the gaseous output. Syngas can be further separated from gaseous output and used for hydrogen production, bio diesel production. Heat recovery is major advantage and it can be used for steam generation.

The exhaust contains CO, CO_2, Hydrogen at high temperature (more than 100°C) and it can be used for thermal energy recovery. The exhaust gas can be further reformed to have better calorific value by addition of steam which will increase the reaction rate to improve the presence of carbon monoxide and hydrogen. Here steam acts as a catalyst. In the existing testing facility steam addition facility is not possible now and it can be one of the future studies to improve the thermal potential and performance.

So thermal treatment of textile sludge with plasma is possible which is confirmed by the experimental studies at various conditions. Further modeling studies can be made to obtain perfect design of plasma reactor and mass and energy balance energy recovery for this plasma treatment of Municipal solid waste and can be studied further.

So to conclude, Plasma technology can be best method applied to treat waste when compared to conventional methods

8. Acknowledgment:

I would sincerely acknowledge the technical support by Bharathiar University thin films laboratory, School of Mechanical Sciences Karunya University and PSG College of Technology. Additional thanks to Dr. S. Balachandran Professor, Dr. S. P. Vendan Associate Professor, Department of Mechanical Engineering PSG College of Technology, Coimbatore for their valuable guidance, extremely useful help and advice in several occasions.

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