Energy and Power from Municipal Solid Waste

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Abstract—**By "The status report on Municipal Solid Waste Management" Central Pollution Control Board (Ministry of Environment and forest), the cities like Nagpur, Mumbai and Pune have generated 650, 6500 and 1300 MT of Municipal Solid Waste (MSW) in the year 2010-11. If this continues, then till 2047 land area equivalent to cities like Hyderabad, Mumbai and Chennai will be under waste, as stated by a 1998 study by TERI (The Energy Resources Institute, earlier Tata Energy Research Institute) titled "Solid Waste Management in India: options and opportunities". Growing population, consumerism and industrial development have led to a dramatic increase in municipal solid waste (MSW) generation. According to Robert A. Frosch and Nicholas E. Gallopoulos "Strategies for Manufacturing", by 2030 there will be 10 billion people on this planet, all ideally with the standard of American life and thus producing as much solid waste as the average American. Apurva Chandra, Joint secretary-marketing, MOP&NG, Government of India in her presentation on "Indian LPG Market Prospects" had mentioned Gap between demand & supply of LPG. Demand for LPG in 2009- 10 stands at 12746 TMT While Indigenous Production in 09- 10 was 10323 TMT hence to cope up this demand Imports of 22% of total LPG was made. Indian government mentions anaerobic digestion, bio-methanation, composting, leachate management etc. ways to tackle this problem. But this trivial waste management system needs separation, segregation and most important thing i.e. human resource to handle such waste. Large amount has to be spent on this while there is no real output as waste is not disappeared from society. Our research has found a way out through plasma assisted gasification of such waste. Plasma-assisted gasification volatilizes MSW in an oxygen-deficient environment where the waste materials are decomposed and partially oxidized to the basic molecules of CO, H2, and H2O. Thus, the organic fraction of the waste is converted into a synthesis gas ("syngas") that contains most of the chemical and heat energy of the waste. The inorganic fraction of the waste is converted into an inert vitrified glass so that there is no ash remaining to be landfilled. Furthermore, the plasma reactor can treat all waste materials, as the only variable is the amount of energy needed to melt the waste. Any kind of feedstock, other than nuclear waste, can be directly processed. The gas jet emerging from the plasma torch can reach temperatures up to 5,000°C. Controlling the temperature of the output gases by modifying the temperature allows a better control of the syngas composition. The potential main advantages of plasma assisted processes, as compared to conventional WTE plants, are the reduction of exhaust gas flow rate, an overall installation with smaller footprint because of more compact equipment, lower capital investment for a given throughput, and faster start-up and shut down times. The process mentioned in our research also favors environmental protection by inhibiting production of hazardous gases.**

***Index Terms*—MSW, gasification, plasma arc, waste to energy(WTE), methane production, plasma torch, plasma reactor.** *(key words)*

I. INTRODUCTION *(HEADING 1)*

Municipal solid waste (MSW) has been identified as a big culprit to cause environmental degradation. Municipals dump MSW in the outskirts of cities. This has proved to be a menace for the society. It was found out that polythene component of MSW was major cause of fury of Mumbai rains on 26th July 2006. According to status report on municipal solid waste management carried out by central pollution control board, India has generated 127485.107 MT/day of MSW in 2009-12. By 'The case of Mumbai, India', by Neelima Rishbud (School of Planning and Architecture, New Delhi), around 6% of Maharashtra's population live in slum areas. By 'The Times Of India', Varanasi, dated 23rd Jan 2014, diseases like typhoid, malaria, dengue, filaria,are results of improper and unscientific methods of MSW management.

The gazette of India mentions anaerobic digestion, bio-methanation, composting, leachate, etc. Ways for disposal and management of waste. But research has told that willingness towards such work and pay scale awarded to such people willing to do such work is not up to the mark. This might be one of the probable reason for slow rate of management of waste. Also govt has to pay a large amount if MSW is to be managed in same trivial fashion (separation and segregation).

Looking at this scenario of India, there is tremendous demand to eradicate waste and associated problems caused. Moreover there are continuous efforts on providing cheap, readily available, sustainable fuel and energy resource to Indian population.

So can we not look at these two problems simultaneously? Yes we can by plasma arc technology. This technology could help us to gasify the waste. This is a modified form of gasification of solid fuels. The partial combustion of solid waste results into a potential gas called syngas, which feeds us energy in our required form.

II. Technologies up till used for waste to energy conversion in India

1. *Anaerobic composting-*

In this method, the waste is exposed to anaerobic microbes, like bacteria, which break down the organic matter in the absence of oxygen. The energy is recovered in the form of biogas and compost in the form of a liquid residual. The liquid slurry can be used as organic fertilizer. Biogas is a very efficient fuel. This process is also termed as Bio-methanation.

2. *Refuse Derived Fuel (RDF)* -

Refused directed fuel is one of the options for energy source from MSW. Refuse Derived Fuel refers to the segregated high calorific fraction of processed MSW. RDF can be defined as the final product from waste materials which have been processed to fulfill guideline, regulatory or industry specifications mainly to achieve a high caloric value to be useful as secondary/substitute fuels in the solid fuel industry. Approx. 33% of MSW is considered as RDF, out of which 70% is combustible. The most important property of RDF is that, unlike coal, it can be derived and manufactured and hence is renewable. RDF is mainly used as a substitute to coal (a fossil fuel) i.e. it could be directly fed to boiler, in high-energy industrial processes like power production, cement kilns, and steel manufacturing. The plant can be kept in operation for about 10 months as plant can't be operated in rainy season, because of obvious reason of high moisture content in MSW.

3. *Pyrolysis:-*

Pyrolysis of solid is chemical cracking of solid fuel in to smaller compounds. Basically it is done by application of thermal energy in oxygen starved atmosphere. The trivial method of pyrolysis consisted of a container deprived of oxygen with heat energy provision from outside it. This resulted in nonuniform, less temperature heating, where proper breaking of compounds could not be guaranteed up to 50% also. Incinerators are one of such examples. They routinely emit dioxins, furans, poly-chlorinated by-phenyls (PCB), which are deadly toxins, causing cancer and endocrine system damage. Other conventional toxins such as mercury, heavy metals are also released. Pollution control costs can exceed over 50% of their installation cost. Hence such measures go against the requirements of Municipal Solid Management rules 2000, which says about source segregation of waste for cleaner composting and recycling. The lessons of incinerating Indian urban waste do not seem to be learnt,, despite of disastrous experience with Dutch-founded incinerator in Delhi. It ran for just one week in 1984, since the calorific value of fuel was less than half of that incinerator needed.

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III. Dis-advantages of these processes

A. *Bio-methanation-*

- It is very slow process. It can't respond to shock loading.
- Non-biodegradable organic matter, refractory turn off cannot be digested.
- Compost can't be directly used as fertilizer.
- It requires expense, non-indigenous
- It technology, hence capital cost is increased.

B. *RDF-*

- It cannot be treated as reliable energy source.
- 22.10% is the only efficiency from MSW as source.
- Separation of waste is hence required, so it would cost more.

C. *Pyrolysis-*

- Though their response is faster than these two, they routinely emit dioxins, furans, poly-chlorinated by-phenyls (PCB), which are deadly toxins, causing cancer and endocrine system damage.

- Their design is mostly fixed for particular quality of fuel.
- More pollutants are transferred in to land, air and water.
- Ash dumping is also an issue with it.

IV. Need according to scenario

Being critical, the waste management sector needs such a solution that would not only provide proper waste disposal with no residue left useless but also it must be efficient enough economically and technically. And it would be cream on cake if it gives us proper energy too in short span of time.

Gasification or pyrolysis is one such solution but combustion of MSW would generate toxic gases like furans, dioxins etc. Pollution standards are very high that amount of suspended particles in atmosphere is 50 ppm. Hence there is need to modify gasification technique.

V. What is plasma?

Plasma or thermal plasma, often called 'fourth state of matter', is a mixture of ions, electrons and neutral particles. It has ability to vaporize solids and destroy any chemical bond. It is created by the ionization of a gas due to the creation of sustained electrical arc between cathode and anode of plasma torch. The gaseous molecules are forced to collide with charged electrons and this creates charged particles. When enough charged particles are created, both positive and negative, the gas starts conducting electricity. Collision between charged particles also occur giving off heat and an arc of light called plasma.

Thermal plasma is plasma close to local equilibrium as the electrons due to their high mobility, maintain ions, atoms molecules - at the same temperature as them; the energy given by electricity is captured by the electrons and is transferred to heavy particles by elastic collision. The ionized carrier gas is projected at high velocity beyond the end of the electrodes as result of high density electric fields, creating a plasma jet.

VI. Plasma arc technology

Plasma technology uses an electric arc to heat gases, typically oxygen, to very high temperature (approximately 3000^0C to 4000^0C). The heated gas can then be used as controlled heat source of a particular application. These applications can include welding, cutting, or disposal. In an application of plasma arc for gasification of waste materials, the amount of oxygen in plasma reactor, as in any gasification system is controlled to eliminate combustion and promote gasification(fig 1.). The extreme heat generated in plasma reactor actually pulls apart the organic molecular structure of the material to produce a simpler gaseous structure CO, H_2, CO_2 etc. As applied to the disposal of waste such as MSW, the gases heated by the plasma arc come into contact with the waste, thereby melting or vitrifying the organic and hydrocarbon (plastic, rubber, synthetic fabric etc.) fraction

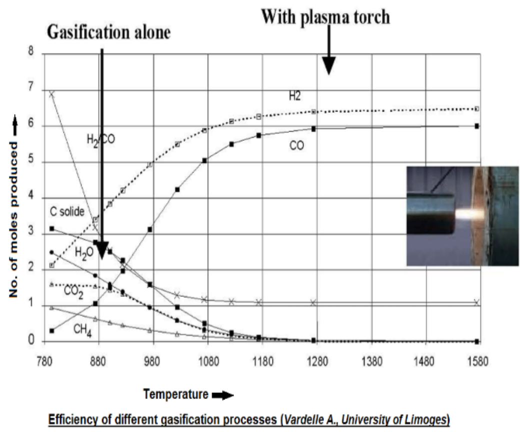

Fig. 1. Efficiency comparison for PAT and conventional Gasification

VII. Municipal solid waste categorization

MSW is the most heterogeneous fuel possible, and it is composed of all sorts of garbage from households(fig 2.). To understand efficiency of this process, it is our interest to analyses the waste stream. The moisture and the different calorific values have a very important and significant on overall process.

On research on MSW, the components of organic material in MSW can be approximated by formula $C_6H_{10}O_4$

Component	Fraction of component (%)	Energy content (kJ/kg)	Heating value of component fraction (kJ/kg)
Kitchen waste	39.24	4180	1640
Fruit waste	8.33	3970	331
Flower waste	0.14	6050	8
Green grass	0.62	6050	38
Dry grass/trees	9.58	15445	1480
Other organic material	3.79	4180	158
Cotton waste	2.48	15445	383
Wood chips/Furnitu	0.95	15445	147

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Plastic	10.14	32799	3326
Paper	7.52	15814	1189
Thermacol	0.19	38191	73
Glass	0.71	195	1
Rubber	0.52	25330	132
Leather	0.67	17445	117
Metal	0.19	-	
Inerts	14.93	-	
Total	100		9022

Fig 2. Calculation of heat value of Mumbai MSW

VIII. PLASMA TORCHES, REACTOR AND OTHER EQUIPMENT

The plasma technology resides in an enclosed reactor into which the waste is fed and processed. The gases in the reactor are heated by one or more torches or electrodes. Plasma can either be generated by DC electric discharge, Radio Frequency and microwaves discharge for treatment of waste, plasma is preferentially generated by Dc electric discharge. For that two kinds of devices can be used- the transferred torch and non-transferred torch.

1. Transferred torch-

In this case, the electricity is transformed to heat within the gas column issued from the torch. The counter electrode is incorporated into the torch and the plasma jet projects beyond it(fig 3.). The electrode is concentric with the jet axis and the arc is transferred to the external electrode. This device is characterized by a relatively large physical separation between the anode and the cathode that ranges between few centimeters to one meter.

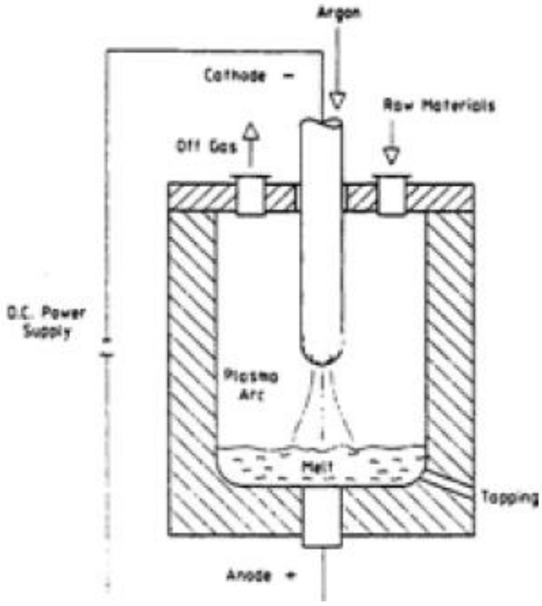

Fig 3. Transferred Plasma torch

As the plasma is produced outside of the water-cooled body of the torch, is allows very high thermal fluxes. This device is more efficient than the non-transferred arc torch as radiant heat transfer losses to the cold torch body are minimized. In fact the cathode can be constructed by either a water-cooled metal or, more usually, by a refractory material that is consumed slowly by sublimation. In this case, the thermal losses are thus greatly reduced but the electrode needs to be often replenished. The anode is made from metal with high thermal conductibility and the key aspect is to provide sufficient water cooling on the back face of the anode to prevent melting as it is the receiver of all the heat. Eventually, despite its lower thermal deficiencies, the most commonly used torch is the non-transferred because it allows the good mixing of the plasma and the waste; and the treatment of the waste does not require the high heat fluxes achieved by the transferred arc.

2. *Non-transferred torch-*

It is the more commonly used device for the waste treatment. Electricity is transformed into thermal energy by means of electric discharges from cathode to anode within a water-cooled torch and heats the plasma jet issued from the torch. It provides a plasma flow for treating the waste and gives a good mixing of the both of them. The arc is established between an axial cathode and an annular anode. The gas crosses the boundary layer between the gas column and the anode inner surface and is pushed downstream by the pressure of the gas flow (fig 4.). The electrodes are large components able to tolerate the gradual abatement and have to be water-cooled to handle the high excursion of temperatures. They have low efficiencies and their power output can be as low as 50% of the power input, which is a main issue. However, it gives a very uniform temperature distribution due to the mixing of the waste within the plasma jet and is easily scaled down to small installations.

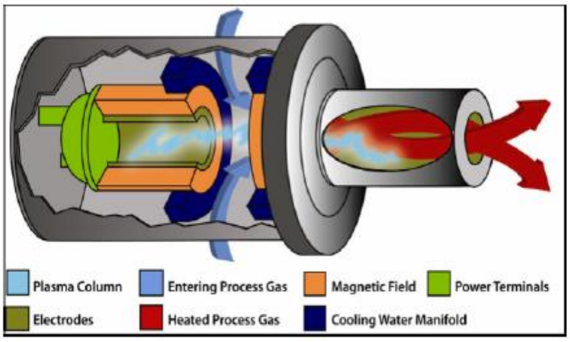

Fig 4. Non-Transferred Plasma Torch

This device can be used in two configurations: with hot electrodes (where the temperature of the plasma is between 6,000 to 15,000K) and cold electrodes (temperature below 7,000K). The main producers worldwide are Europlasma and Westinghouse. Picture shows the Europlasma non-transferred torch(fig 5.):

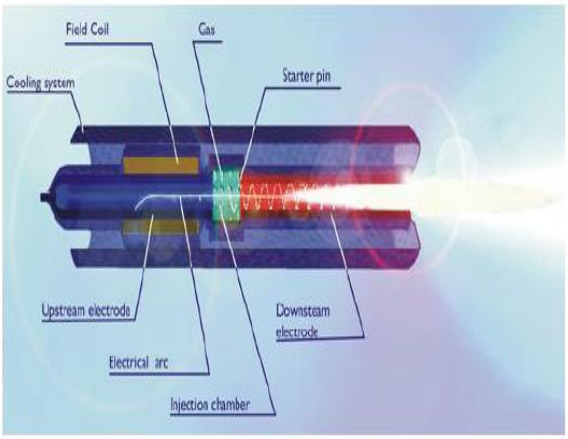

Fig 5. Non-Transferred torch used in Europlasma

3. *Reactor-*

Reactor (fig 6.) is a space that assembles plasma torches and manages waste. The gases and slag material have got continuous outlet openings. The plasma torch is placed inside the reactor itself . This torch can either be a non-transferred torch or a transfer torch. When using a transferred torch, the electrode extends into the waste reactor and the electric arc is generated between the tip of the torch and the conducting receiver, i.e., the metal slag in the reactor bottom or a conducting wall. The low pressure gas is heated in the external arc. Alternatively, a non-transferred torch can be used in which the ionized gas is created within the torch and is projected onto the waste. In each case the electrical source for the torch is direct current. Typically, the waste enters the reactor through a point at the top or the side of the reactor and, after contact with the ionized gas, the metals and ash form a liquid pool at the bottom of the reactor. The organic portion of the waste is gasified, rises, and exits at the top of the reactor. Proponents of the in-situ torch claim its advantages include better heat transfer to the waste and a hotter reactor temperature, resulting in more complete waste conversion. The main disadvantage is the potential corrosive effect of the waste and the gases on the torch in the reactor. Proponents of the external torch point out that this approach protects the torch from the corrosive effects of the waste and prolongs the mechanical integrity of the torches. The disadvantage of the external torch is the possibility of a somewhat lower reactor temperature resulting in less waste being converted. For a graphite electrode, the graphite is consumed over time and needs to be replaced.

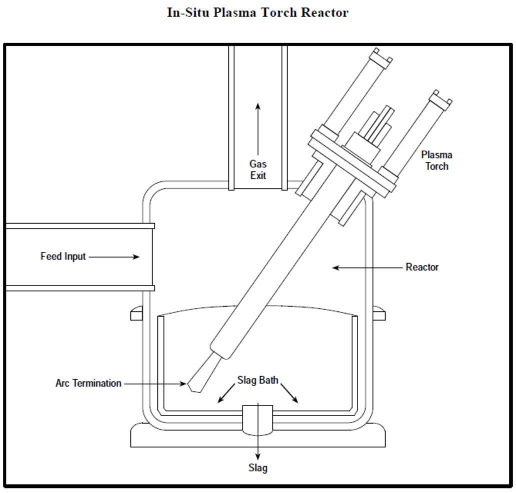

Fig 6. Plasma reactor

4. *Radio frequency heating-*

In a radio frequency heating system(fig 8.), the RF generator creates an alternating electric field causes polar molecules in the material to continuously re-orient them to face opposite electrodes much like the way bar magnets move to face opposite poles in an alternating magnetic field. Friction resulting from this molecular movement causes the material to get rapidly heated throughout entire mass.

The illustration below depicts a radio frequency drying system with material between the electrodes. Polar molecules with in the material are represented by spheres with plus and minus sign, connected by bars (fig 7.).

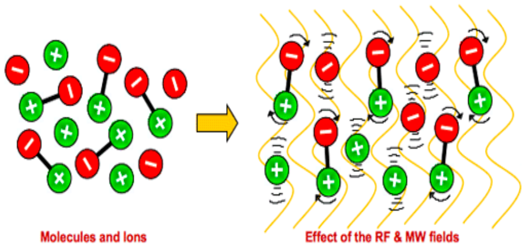

Fig 7. Effect of the RF on MSW

The amount of heat generated by the frequency, the square of applied voltage, dimensions of material and its dielectric loss factor.

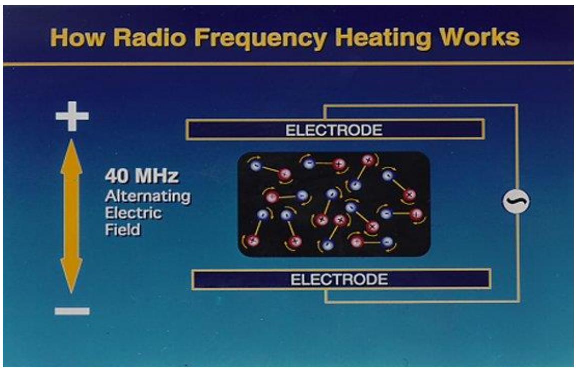

Fig 8. RF heating working principle

5. *Microwave heating-*

Microwave frequencies penetrate conductive materials, including semi-solid substances to a distance defined by the skin effect. The penetration essentially stops where all the penetrating microwave energy has been converted to heat. Instead, the frequency selected allows energy to penetrate deeper into the heated food. The frequency of a household microwave oven is 2.45 GHz, while the frequency for optimal absorbency by water is around 10 GHz. The cavity magnetron (fig 9.) is a high-powered vacuum tube that generates microwaves using the interaction of a stream of electrons with a magnetic field while moving past a series of open metal cavities (cavity resonators). Bunches of electrons passing by the openings to the cavities excite radio wave oscillations in the cavity, much as a guitar's strings excite sound in its sound box. The frequency of the microwaves produced, the resonant frequency, is determined by the cavities' physical dimensions.

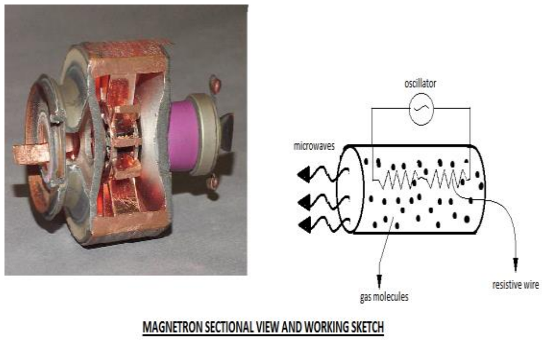

Fig 9. Magnetron sectional view and working sketch

6. *Remaining other equipment(fig 12.)-*

As described by Heberlein and Murphy (2008) “a typical plasma system for treatment of solid wastes consists of

a) the plasma reactor, with collection of the metal (if applicable) and the slag at the bottom, periodically tapped and cast into some usable form, with power supply, cooling water supplies, gas supplies and control and data acquisition equipment,

b) a secondary combustion chamber for allowing sufficient residence time at elevated temperatures 3 to assure complete reactions and gasification of soot; this secondary combustion chamber can be fired either by a burner or by a low power non-transferred plasma torch;

c) depending on the waste, a quenching chamber (usually water quench) to avoid formation of dioxins and furans,

d) a cyclone for particulate removal,

e) a scrubber for eliminating acidic gases,

f) if necessary a hydrogen sulfide absorber,

g) high efficiency filters or precipitators for small particulate removal,

h) an activated carbon filter for removal of heavy metals and

i) Finally a fan for generating sub-atmospheric pressures in the entire installation.

IX. Gasification and Reactions Involved

Gasification is a thermochemical process that generates a gaseous fuel product. There are three kinds of process inside the thermal plasma furnace (fig 10.) for solid waste treatment. First is pyrolysis (under oxygen starvation) of gases, liquid and solids in thermal plasma furnace with plasma torches. Second is gasification (under oxygen starvation) of solid waste containing organic compound to produce syn-gas ($CO+H_2$). Last is vitrification of solid wastes by transferred, non-transferred or hi-breed arc plasma torch according to electric conductivity of substrate.

The main reactions taking place in furnace are-

$C + O_2 \rightarrow CO_2 +$	393 kJ/mol	(exothermic)
$C + H_2O \rightarrow CO + H_2$	- 131 kJ/mol	(Heterogenius water gas shift reaction- endothermic)
$C + CO_2 \rightarrow 2CO$	-172 kJ/mol	(Boudoured equilibrium - endothermic)
$C + 2H_2 \rightarrow CH_4 +$	74 kJ/mol	(exothermic)
$CO + H_2O \rightarrow CO_2 + H_2 +$	41 kJ/mol	(water gas shift reaction -exothermic)
$CO + 3H_2 \rightarrow CH_4 + H_2O +$	205kJ/mol	(exothermic)

As process consist of partial combustion and gasification of waste followed by use of syngas, Gasification by means of partial combustion with oxygen (assuming no reactor heat loss) is given by-

$$C_6H_{10}O_4 + 3O_2 \rightarrow 3CO + 3CO_2 + 4H_2 + H_2O + 1300\ \text{kWh/tonn MSW}$$

This energy can be recovered from sensible heat of syngas. It could also be used to produce steam that can then be used to produce more electricity through steam turbine.

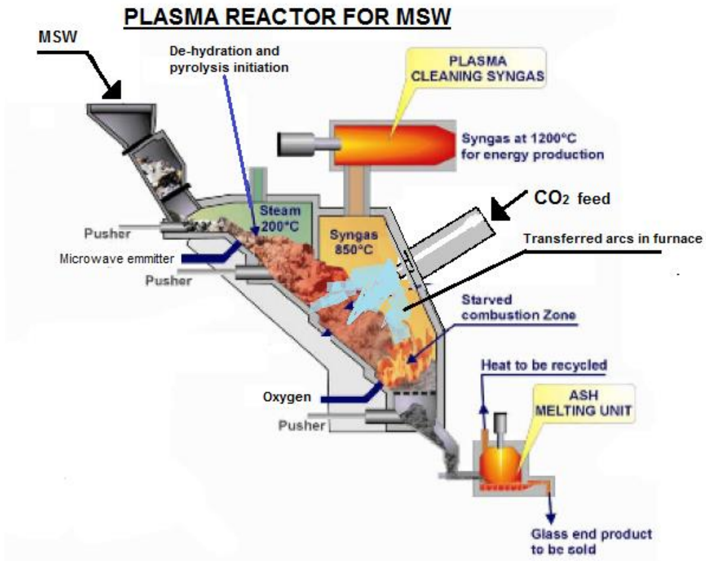

Fig 10. Plasma Reactor for Industrial use

X. Process Diagram

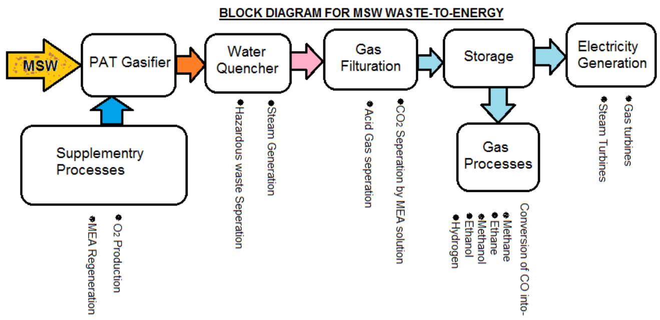

Fig 11. Block diagram for waste-to-energy

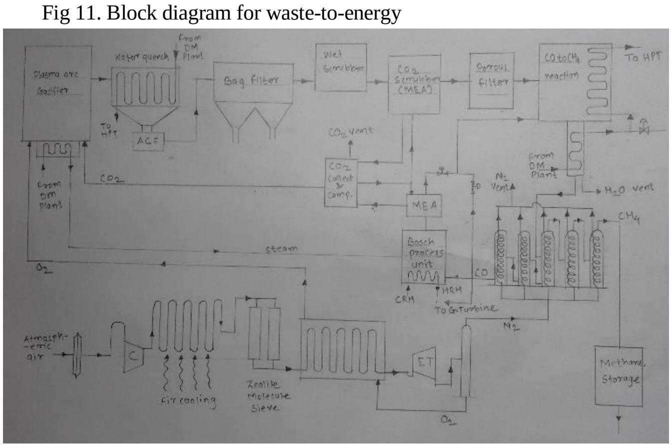

Fig 12. Process diagram for waste-to-energy in industry

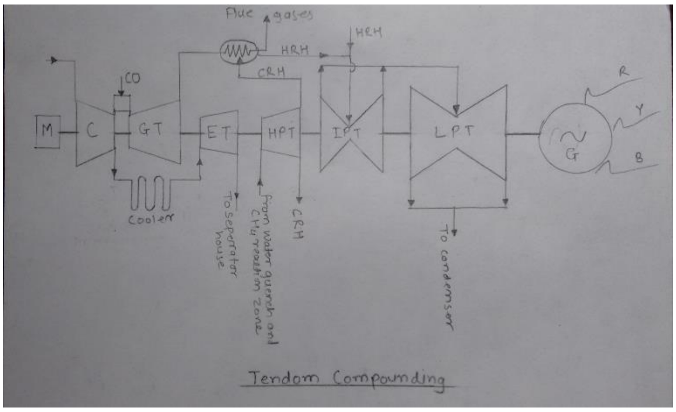

Fig 13. Tendom turbine compounding

XI. PROCESS EXPLANATION

The process starts from introduction of MSW ($C_6H_{10}O_4$) in gasifier reactor (fig 10.). The magnetic scrap is removed first. Remaining waste material is then brought in contact of microwave gun. The role of microwave is to initiate bond braking by increasing their inter-molecular energy of atoms by their misalignment from lattice structure and by direct impact of radiations on atoms and their electrons inside it.

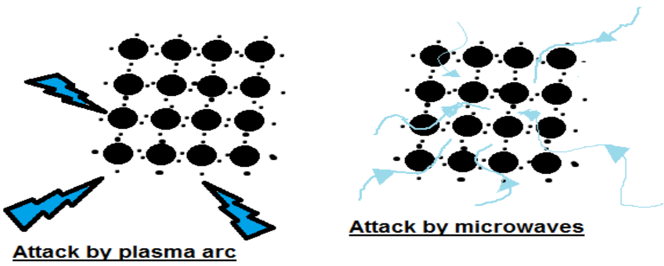

Fig 14. Mechanism of attack by Plasma and Microwave

The power required by such microwave guns is typically 5-6 kWh. While this arrangement is optional but it increases efficiency to grate extent. Heat generated here helps water vapors to vent out.

It then comes in contact of plasma arc (transferred torches). Here MSW gains temperature about 1000^{0}C and absence of O_2 to form tar like substance. This formation of tar like substance is initiation of pyrolysis, while some of substance starts its conversion there only due to inheritant oxygen present in $C_6H_{10}O_4$. Further as it moves down in reactor, it finds O_2 injection. It is pressurized and mixed with carbon dioxide in order to shift equilibrium of reaction towards production of carbon monoxide. Following are gasification reactions-

1) No use of CO_2 atmosphere

$$C_6H_{10}O_4 + 3O_2 \rightarrow 3CO + 3CO_2 + 4H_2 + H_2O + 730 \text{ kJ/mol}$$

2) Use of carbondioxide atmosphere

i) pressure of 10-12 kg/cm^2

$$2C_6H_{10}O_4 + 5O_2 \rightarrow 8CO + 4CO_2 + 8H_2 + 2H_2O + (644 \text{ kJ/mol x } 2=)1288 \text{ kJ/mol}$$

ii) pressure with 50-55 kg/cm^2

$$C_6H_{10}O_4 + 2O_2 \rightarrow 5CO + CO_2 + 4H_2 + H_2O + 558 \text{ kJ/mol}$$

Further the gases evolved are then again treated with non-transferred torch for ensuring total gasification. Ashes and non-combustibles are then also treated with plasma arc to melt them down.

As soon as gases are treated with torch, they are quenched to prevent the formation of dioxins. It may be shell and tube type of heat ex-changer. Further according to Heberlein and Murphy, bag-filters, wet scrubbers, carbon dioxide scrubbers, porous filters are installedfilter. Carbon dioxide filters installed contain Mono Ethanol Amine (MEA) solution with water. Property of this solution is that it dissolves carbon dioxide at room temperature and when heated up will release carbon dioxide and can be used again.

Now the gas treated contain CO, H_2 and traces of CH_4.

Here after gases could be directly used for electricity generation or they could be processed to another form of gas. The reactions that emit heat in gas turbines will be-

$$CO + 1/2\ O_2 \rightarrow CO_2 + 283 \text{ kJ/mol}$$

$$H_2 + 1/2\ O_2 \rightarrow H_2O + 286 \text{ kJ/mol}$$

While the heat rejected by Gas turbine could be used by steam for reheating.

And for processing of gases we have-

$$CO + 3H_2 \xrightarrow[\text{Non-polar atmosphere}]{500^0C} CH_4 + H_2O + 205 \text{ kJ/mol}$$

Above reaction is carried out in the methane conversion Chamber. As the reaction initiates at 500^{o}C, the chamber will be installed with hot water tubes. Hot water tubes will give initiation temperature and then heat generated will be trapped by same water tubes. Still gases escaping will have heat of temperature above 500^oC, so in order to trap that fresh water tubes will be used.

Further the gases produced will be separated out i.e. Methane, carbon monoxide and water. The ratio required for CO and H_2 for conversion is 1:2.25 so total amount of carbon monoxide is not utilized, hence separation is needed. Separation Chambers are series of long vertical columns where gas is uniformly distributed, by principle of density difference they are separated out.

Further CO is serving two purposes. Primary purpose is to get converted in to methane. Second purpose is to run gas turbine. Remembering the ash from furnace. It was reheated. The heat its quenching is stored in the steam. This steam will be used to transform carbon monoxide to methane by Bosch process.

Bosch process is as follows-

$$CO + H_2O \xrightarrow[\text{oxides of Fe with Ni and Cr as promotor}]{550^oC} \underset{(20\%\ \text{by vol.})}{CO_2} + \underset{(79\%\ \text{by vol.})}{H_2} + 41\ \text{kJ/mol}$$

By use of MEA solution, hydrogen could be separated out and will be allowed to react with remaining carbon monoxide further. This will form methane, which will be harnessed along with previously formed methane.

Also oxygen is required for gasification in furnace. Atmospheric oxygen cannot be directly used as there are chances of cyanide and iso-cyanide formation. Hence pure oxygen is required. 95% pure oxygen is prepared in oxygen plant. Air from atmosphere is compressed, cooled, filtered, expanded in turbine. The expansion of turbine causes lowering down of temperature of gas and hence by density difference nitrogen and oxygen are separated out in separator. A heat exchanger is installed so as to make cooled gas super cooled there by supporting density difference separation and make oxygen ready to be used in furnace.

Nitrogen is used in methane and carbon monoxide separation.

The turbine and generators are tendom compounded. The compressor, expander turbine, gas turbine, HPT, IPT and LPT are on same shaft coupled to a generator.

XII. Energy Analysis

The MSW gasification mentioned earlier has application according to input of MSW in plant. Reaction with CO_2 pressure with 10-12 kg/cm^2 is for 1 to 5 tonnes per hour and CO_2 pressure with 50-55 kg/cm^2 is for 6 tonnes/hr and above feed.

Assuming plant to have 10 tonnes/hr capacities and calculating it to ratio of 1 tonne/hr we get-

$$C_6H_{10}O_4 + 2O_2 \longrightarrow 5CO + CO_2 + 4H_2 + H_2O + 558\ \text{kJ/mol}$$

1 gm mole of $C_6H_{10}O_4$ = 12 x 6 + 10 x 2 + 16 x 4

= 156 gm.

Therefore, 156 gm will give 558 kJ of heat

Therefore 10^6 gm will give $\dfrac{10^6 \times 558}{156}$ kJ/tonne

=3576923.077 kJ/tonne

=993.5897 x 3600 kJ/tonne

=993.589 kWh/tonne

Now CO:H_2 = 5:4 in reaction

According to the reaction,

$$CO + 3H_2 \xrightarrow[\text{Non-polar atmosphere}]{500^oC} CH_4 + H_2O + 205\ \text{kJ/mol}$$

1 mole of CO will require 3 moles of H_2

Therefore 1.33 moles of CO will require 4 moles of Hydrogen.

So 3.667 moles of CO are left.

1 mole of CO = 28 gm so 28 gm will give 205 kJ

Also 1 mole of $C_6H_{10}O_4$ i.e. 156 gm gives rise to 5 x 28 gm of CO.

So 1 tonne of $C_6H_{10}O_4$ will give rise to 898 kg of CO.

1 mole equivalent of CO in this case is 180 kg of CO.

Amount of hydrogen produced is $\frac{8\times10^6}{156}$ gm/tonne MSW

=51.28 kg/tonne MSW

First if all gas is used for electricity generation then

Heat obtained from 1tonne of MSW from CO side will be 2521.17 kWhr and Hydrogen side is 2037.037 kWhr (by molar calculations). So total energy is 4558.037 kWhr. Considering 50% efficiency of combined cycle power plant then electricity obtained will be 2279.10 kWhr.

While electricity obtained by steam turbine at 40% efficiency will be 993.589x0.4= 397 kWhr

Adding both we get 2676.53 kWhr. But total consumption of energy to run main supplementry units is (245+75=) 320 kWhr.

So net electricity that could be sent on grid is 2036 kWhr = 2MW (approx.)/tonne of MSW.

Secondly if method of process is adapted then-

28 gm of CO gave 205 kJ

There fore 180 kg of CO gives rise to $\frac{205\times180\times10^3}{28}$ kJ/tonne of MSW

= 1314102.56 kJ/tonne of MSW

=365 kWh/tonne MSW

Now after separation from methane, carbon monoxide is transformed in to

1. Hydrogen by Bosch process
2. Electricity by gas turbine.

1. Carbon monoxide to Hydrogen by Bosch process

No. Of moles remaining were 3.667. Using 1.67 for electricity generation we have 2 moles of CO. Hence utilizing $1\frac{1}{2}$ moles for hydrogen generation and remaining half mole for its reaction with hydrogen thus formed.

Bosch process is exothermic liberating 41 kJ/mol.

Therefore 270 kg of CO will produce = $\frac{270\times10^3\times41}{28}$

= 395357.1429 kJ/tonne MSW

= 109.821 kWh/tonne MSW

2. Carbon monoxide to Electricity by gas turbine

1.67 moles of CO is equivalent to 300 kg of it.

Combustion of CO gives 283 kJ/mole

$$CO + 1/2\ O_2 \longrightarrow CO_2 + 283\ kJ/mole$$

Therefor 300 kg gives = $\frac{283\times300\times10^3}{28}$

= 3032749.286 kJ/tonne MSW

=842.43 kWh/tonne MSW

And power required by oxygen plant is 75 kWh/tonne (mechanical on shaft)

Power required for torches is 240 kWh/tonne MSW and 5 kWh/tonne MSW for microwave gun = 245 kWh/tonne MSW (electrical)

There fore power is = 993.589+365+109.821

= 1468.409 kWh/tonne MSW

By steam side, considering 40% efficiency of turbine, we get 587.363 kWh/tonne

Gas turbine combined cycle efficiency be 50% so 842 x 0.5 = 421.215 kWh/tonne

There fore power on shaft will be 1008.57 kWh/tonne MSW

So oxygen plant requirement is75 kWh/tonne MSW.

Therefore 1008.5786-75=933.578 kWh/tonne MSW

Electricity generated= 933.578 x 0.98 = 914.9 kWh/tonne MSW

Plasma torches require 245 kWh/tonne MSW

There fore total output power obtained will be 700 kWh

Methane given out by process is 1.33 + 0.5 moles i.e. 1.83 moles

1 mole methane is equals to 20 gm

If 1 mole MSW compound gives 1.83 mole i.e 156 gm MSW gives out 20 x 1.83 = 37 gm

Then one tonne of MSW gives out $\frac{10^6 \times 37}{156}$ = 237.18 kg methane

Let the cylinders packing be of 14 kg

There fore per hour per tonne MSW $\frac{237}{14}$ = 16.94 ≈ 16 cylinders are made.

XIII. ADVANTAGES OF THERMAL GASIFICATION

1. High energy density and temperatures, and corresponding fast reaction time, offer the potential for a large throughput with a small furnace.
2. High flux density at the furnace boundaries lead to fast attainment at steady state conditions. This allows rapid start-up and shutdown time compared with other thermal treatments such as incineration.
3. Only small amount of oxidant is necessary to generate syngas, therefore, the gas volume produced is much smaller than with conventional combustion process and so is easier and less expensive to manage.
4. Due to use of high temperatures, there is no chance for any waste residue , left in furnace. Except stones which are not waste, hence separated previously. Only refractory material is sent out which is up to 15% of total volume. Considering all the possibilities in furnace, its efficiency is around 99% approx.

XIV. VARIOUS SECTORS OF APPLICABILITY OF PLASMA ARC TECHNOLOGY

1. In 19 th century the metal industries of Europe started using Plasma for metal extraction and refining.

2. In 20th century, extraction of acetylene gas from natural gas started.

3. Since 1960, NASA of United States used plasma technology to simulate high temperature that orbiting space vehicles would encounter when re-entering earth's dense atmosphere.

4. Research is going on to convert plastic to paper using plasma arcs.

5. Nuclear fission reaction uses proton. Hydrogen is passed from plasma environment and protons are collected.

XV. ENVIRONMENTAL IMPACT ASSESSMENTS

A. *Solid residue-*

Both WTEs and plasma facilities produce solid residue. Approximately 25 percent of the MSW throughout in a typical WTE results in bottom and fly ash. Depending on the air pollution control system employed, approximately the same percentage of throughput would be produced, in the form of slag and other residue, from a plasma facility disposing of MSW. A WTE or plasma facility with a throughput of 200 tonnes per day of MSW would produce approximately 50 tonnes per day of solid residue. The environmental impact of the solid residue from these facilities would be determined in the same way. However, the slag from a plasma reactor should have some beneficial use.

Following are the solid residue obtained from various MSW WTE plants.

TCLP Toxicity Limits and Test Results for Slag and Ash (all units in ppm)				
	USEPA Toxicity Limits	PEPS Facility	PEPS Facility	H-Power Plant
Feedstock		RMW	ABM	MSW
Arsenic (As)	5.0	0.200	0.200	0.025
Barium	100	NA	NA	0.66
Cadmium (Cd)	1.0	0.140	0.100	0.005
Chromium (Cr)	5.0	0.720	0.200	0.005
Lead (Pb)	5.0	0.730	0.200	0.025
Mercury (Hg)	0.2	0.020	0.020	0.00029
Selenium (Se)	1.0	0.500	0.500	0.025
Silver (Ag)	5.0	0.100	0.100	0.005

Fig 15. Solid residue obtained from various MSW WTE plants.

B. Water residue-

The water coming out from wet scrubbers could be managed by $NaHCO_3$ as titration. Or ash coming out is mostly basic in nature. The acids trapped in water could be neutralized and remaining water could be sunk down to ground through sand filters.

C. Gaseous residue-

Carbon dioxide and nitrogen are vented out from plant purposefully. As carbon dioxide is not pollutant but a greenhouse gas it's not matter to be worried. Suspended solid particles in air are to be 50 ppm. According to process, plasma torches work with 99.8% efficiency hence no solid residue could be left.

Some hazardous waste such as mercury, arsenic, lead get converted in to vapors and as soon as they come back in their original form, activated carbon filter will take care of all such materials. Environmental services facility there after takes the charge. (ph- 604-822-6306)

XVI. Conclusion

The demand of energy is increasing by leaps and bonds, due to the ever increasing population. Another problem faced by mankind is waste disposal without effecting the ecology. This project aims to target both there burning topics. The hazardous waste as well as MSW, which has proved to be a nuisance to the society in terms of environment sanity, contains a high amount organic content that can be derived in to fuels.

Traditionally landfills were used as disposing medium of the urban areas but it was not environmentally safe. It also required large dumping area, which are of prime importance in developing nations. By using this technology the need of landfills are nearly eliminated as also the need and cost of transportation of wastes.

Despite many advantages of this WTE conversion technology there are some serious issues, which need to be addressed for economical implementations. In the view of low level complacence of MSW rules 2000 by the Municipal solid waste is generally not available at plant site, which may lead to non-availability of waste for plants. But by the passage of time dumping yards could be constructed nearby plants itself.

This technology is gaining popularity around world. The ministry of New and Renewable Energy Sources (MNES), govt. Of India, have recognized the importance of these technologies and are providing necessary aids to encourage the usage.

There are many private and public enterprises are implementing these technologies in India. In future there may be more plants coming up in many cities thus reducing the hazard of toxic waste coming from urban areas, hospitals and industries. Thus this technology must be encountered, as it is capable of transforming bane into boon!

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