Advance Technologies for treatment of Municipal Solid Waste

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Abstract
This is an emerging technology utilizing thermal decomposition of organic wastes for energy/ resource recovery. Energy may be conserved by the reclamation of waste materials in two principal ways. First, David Gordon Wilson. fuels or thermal energy may be obtained. Second, when materials are recovered and are used in place of virgin materials, a considerable saving in processing and transportation energy normally occurs. Any waste handling, treatment and disposal facility, either for energy/resource recovery (including compost) or only for waste destruction, cab be a source of environmental pollution (air/ground/water and land/visual/noise/odour pollution/explosion), unless proper measures are taken in its design and operation. The Major environmental concerns in case of the Waste-to-Energy facilities based on the established technologies of Incineration and Anaerobic Digestion and the control measures .Incinerators burning MSW can produce a number of pollutants in the flue gas in varying concentration like carbon monoxide, sulfur dioxide, and particulate matter containing heavy metal compounds and dioxins. Many of these pollutants are formed as a result of incomplete/Partial combustion. That is refuse that is not burned at high enough temperatures, for long enough or when too much or too little air has been added to the fire. The generation of these pollutants and their release into the atmosphere cab be effectively reduced or prevented by incorporating a number of air pollution control devices like bag filter, ESP, Cyclone and Scurbber and by proper operation of the WTE facility. The waste to energy plant in India successfully operated but plasma gasification plant till now in India not operating for the Indian municipal solid waste . About 92 Plants with aggregate Capacity of 250 MW have been setup in the country to Electricity generation on an average 100 ton per day of MSW is required to generate 01 M.W. of Power India is betting high at WTE plants. The NITI Ayog has a target of construction WTE Plants with Total Capacity of 330 MW in 2017-18 at another 511 MW in 2018-19 under the Suachh Bharat Mission.

***Keywords*: Waste to energy plant, Plasma gasification, Scrubber, dioxins**

**Table (1) Major MSW generating of States
(Financial Year 2019)**

S.No.	*State*	*MSW Generation*
1	Maharashtra	23,844 MT/Day
2	U.P.	17377 MT/Day
3	West Bengal	14613 MT/Day
4	Tamil Nadu	13968 MT/Day
5	Karnataka	11958 MT/Day
6	Delhi	10817 MT/Day
7	Telangana	8497 MT/Day
8	M.P.	8000 MT/Day
9	Rajasthan	6625 MT/Day
10	Andhra Pradesh	6440 MT/Day
11	Haryana	4635 MT/Day
12	Punjab	4635 MT/Day
13	Kerala	3900 MT/Day

(CPCB Data)

Table (2) Major MSW generating of Cities

S.No.	*Rank City*	*Population (2011)*	*Waste Generation*	
			2010-11	*2015-16*
1	Mumbai	12,442,375	6500	11,000
2	Delhi	11,034,555	6800	8700

3	Bangalore	8,443,675	3700	3700
4	Chennai	7,088,000	4500	5000
5	Hyderabad	6,731,790	4200	4000
6	Ahmadabad	5,577,940	2300	2500
7	Kolkata	4,496,694	3670	4000
8		4,467,797	1200	1680
9	Pune	3,124,458	1300	1600
10	Jaipur	3,046,163	310	1000
11	Lacknow	2,817,105	1200	1200
12	Kanpur	2,765,348	1600	1500
13	Nagpur	2,405,665	650	1000
14	Visakhapatnam	2,035,922	334	350
15	Indore	1960631	720	850
16	Bhopal	1798218	350	700

(CPCB Data)

Table (3) Overall Solid Waste Management States 2020-21

S.No.	***State***	***Solid Waste Generated TPD***	***Collected TPD***	***Treated TPD***	***Land filled TPD***
1	Andhra Pradesh	6898	6829	1133	205
2	Gujarat	1037379	10332	6946	3385
3	Haryana	5352	5291	3123	2167
4	M.P.	80225	72355	6472	763.5
5	Maharashtra	2263271	22584.2	15056.1	6221.5
6	Punjab	4338	4278	1894	2384
7	Rajasthan	6897	6720	1210	5082
8	Delhi	10990	10990	5193	5533

(CPCB Data)

Table (4) Solid Waste Generation per Capita

S.No.	***Year***	***Solid Waste Generation per Capita (Gram/Day)***
1	2015-16	118.68
2	2016-17	132.78
3	2017-18	98.79
4	2018-19	121.54
5	2019-20	119.26
6	2020-21	119.07

(CPCB Data)

Table (5) Physical Characterises of MSW in Indian Metro cities charted in (% by weigh)

S.No.	***Name of Metro City***	***Paper***	***Textile***	***Leather***	***Plastic***	***Metals***	***Glass***	***Ash Fine earth***	***Compostable matter***
1	Ahmadabad	6.0	1.0	-	3.0	-	-	50.0	40.00
2	Bhopal	10.0	5.0	2.0	2.0	-	1.0	35.0	45.00
3	Bangalore	8.0	5.0	-	6.0	3.0	6.0	27.0	45.00
4	Mumbai	15	3.14	-	-	0.80	0.40	35.0	37.5
5	Delhi	3.62	0.52	0.85	4.17	0.45	0.49	36.56	-
6	Chennai	6.45	-	1.45	7.04	0.03	-	34.65	47.24

Table (6) Waste Generation and its characteristics in Indian cities

Population in range (in million)	***Average per capita waste generation (kg/capita/day)***	***Municipal solid waste characteristics***			
		Compostable fraction (%)	***Total recyclables (%)***	***C/N ratio***	***Calorific value (kcal/kg)***
<0.1	0.17-0.54	29-63	13.68-36.64	18-37	591-3766
0.1-0.5	0.22-0.59	29-63	13.68-36.64	18-37	591-3766
0.5-0.1	-	35-65	11-24	17-52	591-2391

1.0-2.0	0.19-0.53	39-54	9-25	18-52	520-2559
>2.0	0.22-0.62	40-62	11-12	21-39	800-2632

Source : NEERI Report (2005)

I. Different Technological Options

The details of different technological options :

(a) Anaerobic Digestion

Energy recovery with production of high grade soil conditioner. No power requirement unlike aerobic composting, where sieving and turning of waste pile for supply of oxygen is necessary. Enclosed system enables all the gas produced to be collected for use. Controls Green House Gases Emission. Free from bad odour, rodent and fly menace, visible pollution and social resistance. Heat released is less-resulting in lower and less effective destruction of pathogenic organisms than in aerobic composting. However, now the rmophilic temperature system is also available to take care of this. Unsuitable for wastes containing less organic matter. Requires waste segregation for improving digestion efficiency.

Modular construction of plant and closed treatment needs less land area. Net positive environmental gains. Can be done at small-scale

Land fill Gas Recovery. (Least cost option)

The gas produced can be utilized for power generation or as domestic fuel for direct thermal applications. Natural resources are returned to soil and recycled. Can convert low lying marshy land to useful areas.

Greatly polluted surface run – off during rainfall. Soil / groundwater acquifers may get contaminated by polluted leachate in the system. Inefficient gas recovery process yielding 30-40% of the total gas generation. Balance gas escapes to the atmosphere (significant source of two major Green House gases, carbon dioxide & methane) Large land area requirement Significant transportation costs to faraway landfill sites may upset viability. Cost of pre treatment to upgrade the gas to pipeline quality and leachate treatment may be significant. Spontaneous ignition/explosions due to possible build up of methane concentrations in atmosphere.

(b) Incineration

Most suitable for high Calorific Value waste, pathological wastes, etc. Units with continuous feed and high through-put can be set up. Thermal Energy recovery for direct heating or power generation. Relatively noiseless and odorless. Low land area requirement. Can be located within city limits, reducing the cost of waste transportation. Least suitable for aqueous/ high moisture content/ low Calorific Value and chlorinated waste. Excessive moisture and inert content affects net energy recovery; auxiliary fuel support may be required to sustain combustion. Concern for toxic metals that may concentrate in as, emission of particulates, SOx, NOx, chlorinated compounds, ranging from HCL to Dioxins. High Capital and O&M costs. Skilled personnel required for O&M Overall efficiency low for small power stations.

(c) Pyrolysis / Gasification

Production of fuel gas/ oil, which can be used for a variety of applications. Compared to incineration, control of atmospheric pollution can be dealt with in a superior way; in techno-economic sense.Net energy recovery may suffer in case of wastes with excessive moisture. High viscosity of pyrolysis oil may be problematic for its transportation &burning.

II. Land Requirements of MSW Technology:-

The area of land required for setting up any Waste Processing/Treatment facility generally depends upon the following factors:

(a) Total waste processing/treatment capacity, which will govern the overall plant design/size of various sub-systems.

(b) Waste quality/characteristics, which will determine the need for pre-processing, if required, to match with the plant design.

(c) Waste treatment technology selected, which will determine the waste fraction destroyed to energy.

(d) Quantity and quality of reject waste, liquid effluents and air emissions, which will determine the need for disposal/post treatment requirements to meet EPC norms.

As such, the actual land area requirement can be worked out only in the Detailed Project Report for each specific project. However, for initial planning the following figures may be considered for 300 TPD (input capacity) Waste-to-Energy facilities.

Incineration/Gasification/Pyrolysis plants : 0.8 hectare*
Anaerobic Digestion Plants : 2 hectares*
Sanitary Landfills (including Gas-to-Energy recovery) : 36 hectares**
Based upon typical installations

For areas away from coast (can be more in coastal areas). This is estimated on the basis of a filling depth of 7m and Landfill life of 15 years.

III. Principal feedstock preparation steps for biomass gasification

(a) **Sizing**

Smaller particles have a larger surface area to volume ratio, and the gasification reaction occurs faster when there is a larger biomass surface area. Smaller particles can also be suspended in gas flows more readily, and if very small, the particles may act like a fluid, achieving the correct feedstock sizing for the gasifier is important. Crude sizing operations include chipping, cutting and chopping, but in order to get very small ground particles, pulverizing milling equipment is needed, this is an energy intensive process. A screening process is often used to ensure any remaining larger particles and extraneous materials removed.

(b) **Drying**

The removal of moisture contained within the biomass by evaporation, typically using temperatures between 100^0 C and 120^0 C. Drying requires a significant amount of energy in order to evaporate the large mass of water. This heat can be provided externally, or extracted from the gasifier syngas or other plant process steps. Gasification efficiency increasing with drier biomass, but drying costs also increased quickly below 10% moisture.

(c) **Torre faction**

A mild thermal treatment (approximately 30 minutes at between 200^0 C and 300^0 C, in the absence of oxygen) resulting in a low-oxygen content, dry and reltively brittle product.Torrefied wood is much easier to grind than untreated wood, using 80% less energy for a given sizing, and with a significant increase in milling plant capacity.

(d) **Pyrolysis**

The thermal degradation of biomass in the absence of oxygen, whereby the volatile parts of a feedstock are vaporized by heating. The reaction forms three products : a vapor that can be condensed into a liquid (pyrolysis oil), other gases, and a residue consisting of char and ash. Fast pyrolysis processes are designed and operated to maximize the liquid fraction (up to 75% by mass), and require rapid heating to temperatures of 450^0 C to 600^0 C, and rapid quenching of the vapors to minimize undesirable secondary reaction. The resulting liquids and solids can be ground together to form a bio-slurry for gasification.

(e) **Plasma Gasifiers**

Plasma gasification usually takes place in the absence of a gasification oxidant, with some gas (e.g. air, oxygen, nitrogen, noble gases only present to produce the plasma in the jet or arc, for the provision of heat. Extremely high temperatures (greater than $5{,}000^0$ C) ensure that the feedstock is broken down into its main component atoms of carbon, hydrogen and oxygen, these quickly re-combine to form hydrogen and carbon monoxide gases, thereby producing a very high quality syngas, with no methane, hydrocarbons or tars. Other plasma gasifiers work at lower temperatures (from $1{,}500^0$ C TO $5{,}000^0$ C, but still well above EF conditions), producing some tars and hydrocarbons, which are them immediately cracked. Plasma torches have highly adjustable power outputs, hence temperatures and syngas components can be controlled. Since plasma gasification usually uses waste feedstock, chlorides levels can be high, which can lead to high levels of impurities (such as dioxins and metals) in the syngas, although many of the heavier elements are vitrified and hence safely removed. As it has been one of the best proven methods for treating municipal solid waste it may be employed in every municipal corporation. Treatment of solid waste by various other methods may involve certain difficulties for the complete disposal of residues. As far as plasma gasification is concerned the total disposal residues is possible hence there will be no need of leaving any residues that may cause further problem. In order to make it more accessible and affordable to all, the equipment related to the process may be made available at reasonable expenses by innovative design.

IV. Compression between Plasma Gasification over Landfills:

Gasification is superior to landfilling MSW for a number of reasons. Landfill is toxic to the environment due to the production of toxic liquid leachate and methane gases. Decomposition and chemical reactions among the waste produces liquids that leach out and may contaminate ground water. Decomposition of organic matter produces methane, which is a potent greenhouse gas. Other chemicals may be produced that toxify the air around a landfill and may be harmful to neighbors. The EPA has a lengthy protocol of airborne and liquid chemicals that must to contained and monitored into eternity for every landfill. Modern landfills must be constructed with liners and leachate drains. These facilities area becoming increasingly expensive as more environmental regulations come into existence. When landfills are closed, they must be capped and monitored indefinitely. Despite expensive management strategies, the only good solution for landfills is to avoid them. Plasma gasification is an ideal treatment strategy to divert waste from landfills and create beneficial uses for the material by maximizing recycling of valuables and cleanly use the rest for its fuel value. The carbon impact of plasma gasification is significantly lower than other waste treatment methods and is rated to have a negative carbon impact compared to allowing methane to form in landfills.

V. Compression between Plasma Gasification over Incineration:

Gasification is superior to incineration, and offers dramatic improvement in both its environmental impact as well as its energy performance. Incineration has long had problems with the formation of dioxins and other critical pollutants. Incinerators are high-temperature burners that use the heat generated from the fire to run a boiler and steam turbine to produce electricity, very similar to conventional coal-fired power plants. During combustion, complex chemical reactions take place that bind oxygen to various molecules and form pollutants such a sulfur oxides, nitrogen oxides and dioxins. These pollutants pass through the smokestack unless exhaust scrubbers are put in place to clean the gases. Gasification by contrast is a low oxygen process, and fewer oxides are formed. The scrubbers for gasification are placed in line and are critical to the formation of clean gas. Scrubbers in a gasification system are integral to the operations of the system regardless of the regulatory environment. For combustion systems, the smokestack scrubbers offer no operational benefit and are put in place primarily to meet legal requirements. The ash from incinerators is also highly toxic and is disposed of in landfills, while the slag from plasma gasification is safe because all of the ash is melted and reforms in tightly bound molecular structure.

VI. Comparison of Plasma Gasification Technology with Conventional Disposal Methods

Plasma gasification technology is a method which has many purported advantages in waste management in comparison to other conventional disposal method. Plasma gasification method can be applied to almost all kind of wastes, except nuclear wastes, however, other conventional methods may not. Additionally, it require minimal presorting of solid wastes unlike other conventional methods such as incineration. Plasma gasification technology is more environmentally friendly method than the other treatment methods in terms of by-products. While syngas, which mainly comprise CO and H2, can be used for producing energy, vitrified slag can be utilized to generate rock wool floor tiles, roof tiles etc. In addition to producing environmental friendly by –by product, this technology has important advantages over conventional methods in terms incineration gas emission. While high amounts of harmful gases are sent to the atmosphere in incinerations or land filling method, much lower emission is produced in plasma gasification technique. Therefore, plasma gasification can be thought as an effective alternative method that can be used instead of land filling and incineration method due to these environment advantages .in addition to environmental advantages of plasma gasification method over conventional disposal techniques, it has economic advantages too. Plasma gasification technique has more revenue sources than the other techniques and these revenue sources can be generally stated as production of electricity, tipping fees, sales of slag and recyclables. Among these revenue sources, generation of electricity can be very important factor. For example, while 816 kWh electricity can be generated from same amount of MSW by mass burn technology. Therefore, this difference affects revenue amount significantly. Plasma gasification technology especially has many advantages in comparison with incineration method one common conventional techniques for municipal waste disposal. Incineration and plasma gasification method is compared with each other based on selected seven criteria.

Table (7) Comparison of incineration and plasma gasification method

Criteria	***Incineration***	***Plasma Gasification***
Emission of pollutant	High	Very Low
Material recovery	Lower	Higher
Energy recovery	Lower	Higher
Formation of ash	Exist	No exist
Disposal cost for by-products	Exist	No exist
Moisture of waste	Important	Not Important
Sorting of waste before feeding	Important	Not Important

VII. Plasma Arc Gasification For Waste Management And Sustainable

Renewable Clean Energy Generation

Plasma gasification in waste to energy is one of the novel applications that were introduced many years ago. Landfill sites and incineration continue to be the primary methods used to dispose waste 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 know fact that incinerator ashes are contaminated with heavy metals, unburned chemicals and new chemicals formed during the burning process. There ashes are then buried in landfill or dumped in the environment. Rather than making waste disappear, incinerators create more toxic waste that pose a significant threat to public health and the environment. Sustainable and successful treatment of MSW should be safe, effective, and environmentally friendly. In this application, plasma arc gasifies the carbon-containing materials in the waste to produce synthesis gas (syngas) composed primarily of carbon monoxide and hydrogen, which can be used to produce energy through reciprocating engine generators – gas turbines and steam boilers in integrated gasification combine circle (IGCC), and/or liquid fuels. The in-organic waste materials are vitrified and runs out of the vessel's bottom as glass-like slag and reusable metal. The double benefit of waste management and energy production is realized from plasma gasification process.

Table (8) Output Gas Composition

Output Gas	*Ex-situ Experiment Without soil (PPM)*	*In – Situ Experiment With soil (PPM)*

Hydrogen (H2)	>20,000	>20,000
Carbon Monoxide (CO)	100,000	>100,00
Carbon Dioxide (CO2)	100,000	90,000
Nitrogen Oxides (NOx)	<50	100
Hydrogen Sulfide (H2S)	100	80
Hydrogen Chloride (HCL)	<20	225
Hydrocarbons	>5,000	<4,500

PPM = Parts per million

Table (9) Plasma Gasification Compared to Incineration and other Gasification Process

Feedstock Flexible	***Ease of Operation***	***Environmental Benefits***	***Flexible Product Delivery***
A wide range of opportunity fuels can be accepted with limited pre-processing requirements	The Gasification Reactor Operates at ambient pressures allowing for simple feed system and online maintenance of the plasma torches	Operations is environmentally responsible creating a product gas with very low quantities of NOx. SOx. Dioxins and furans	Syngas composition (H2 to CO ratio, N2) can be matched to down stream process equipment by selection of oxidant and torch power consumption
Multi feed Stocks can be combined	Plasma Torches have no moving parts resulting in high reliability. Torch consumables are quickly replaced off line by plant maintenance personnel	Inorganic components get converted to glassy slag safe for use as a construction aggregate	Multiple gasification reactors are used for larger projects increasing available of the gasification system

VIII. Waste Management criteria

There is an emerging global (RathiSarika, 2007, Patel M.L. Chauhan J.S., 2012) consensus to develop local level solution and community participation for better MSW management. Emphasis has been give to citizens' awareness and involvement for better (Beukering, 1999 waste management. A number of studies were carried out in the past of compare different methods of waste disposal and processing for different places. (Mainmone, M., 1985) concluded that composting was the best option of waste management. (Powell, J.C., 1996) concluded that refused derived fuel was the best option. It can be inferred from the literature that no one method in isolation can solve the problem of waste management. The present study is an attempt to establish that the best feasible method of waste management shall involve plasma gasification method which will not only achieve environmental sustainability but also sustainable renewables energy solutions. The suitability of a particular technology for the treatment of MSW depends on a number of factors which includes techno-economic viability, environmental factors sustainability, (Sanitation, kerala.gov.in/pdf/ workshop/ techno _2pdf, accessed during December 2011), (Verma, R. Ajay kumar, 2009) and geophysical background of the location. The plasma gasification process (Liza Zyga, 2012), seems to be a realistic solution for the MSW Management. It is a process that can get rid of almost any kind of waste by eliminate existing landfills, open dumps, and a clean renewable energy.

IX. Sustainability Criteria

The sustainability of any project depends up on the capital cost, running & maintenance cost, availability of raw materials and payback cost. Capital costs for a plasma gasification plant are similar to those for a municipal solid waste incineration power plant, but plasma gasification plants are more economical because the plant's inorganic byproduct cab be sold to the market as bricks and concrete aggregate. Plasma gasification plants also produce up to 50% more electricity than other gasification technologies, (Pourali , M. 2010) hence, reducing the payback period. Nedcorp group plasma gasification system using Westinghouse Plasma Corporation plasma touches uses 2 to 5% of energy input to produce 80% of energy output (Anyaegbunam F.N.C., 2013) The raw material or fuel for the plant is readily available in abundance and increasing by the day. Typical plasma gasification for waste to energy plant with a feedstock of 3,000 MT of MSW per day is estimated to cost over $400 million for installation and will generate about 120MW of electricity (Pourli, M. 2010). Most of the Plasma Gasification Plant require 120 Kwh of energy per ton of MSW and 816 kwh electricity is generated from the process. It is also projected (Pourali, M. 2010) that each ton of MSW can produce 1.20 MWh of electricity if an integrated gasification combine circle (IGCC) is used. As the technology continues to gain acceptance, the cost will decrease significantly. Thus, theoretically, plasma IGCC plant at 45% efficiency can generate about 1,035MWh of electricity from 1918 MT of MSW.

X. Sanitary Waste Disposal

The sanitary items including masks, sanitary napkins, diapers etc, are disposed-off utilizing high temperature plasma. The MSW facility is equipped with special disinfection capabilities to help break the COVID Chain through UV-C Lights and Hot-Air Convection methods. The decentralized Solid Waste Management Plant developed by CSIR-CMERI has all the potentials to scientifically manage the Solid Waste including the COVID and other viruses present in the wastes. The integrated MSW pilot plants is also self-sufficient in terms of energy requirement through the installation of roof-mounted solar panels, which can also feed the surplus energy supply onto a mini-gird. The technology of decentralized (0.5 to 5.0 ton/day) MSW and its sustainable (negligible transport to reduce the burden of imported diesel and created CO2pollution) processing opens- up the opportunities to realize the dream of generating 100 GW Solar Power and a city with a ‘‘Zero-Waste and Zero-Landfill Ecology’’, and may become a ‘‘Source of Job Creation’’ through both process- engagement and manufacturing, which can help support the MSEs, Start-Ups and numerous Small Entrepreneurs across the Nation.

XI. Results and discussion

Municipal Solid Waste Management is a great challenge to the Waste Managers, Scientists and Engineers. The quantity of Municipal Solid Waste generation is increasing and availability of land for the landfills or open dump disposal is decreasing day by day and hence most of the latest efforts focus on ‘‘Zero Waste’’ and/or ‘‘ Zero Land filling’’ disposal methods. It is depicted from the data interpretation that; that average Municipal Solid Waste generation. The percentage of plastic waste present in municipal solid waste is about 8% on average. The Plasma Gasification Process of Municipal Solid Waste is a proven technology in which the weight is reduced by about 84% and the volume of organic matter reduced by more than 95%. The vitrified glass generated as residue from Plasma Gasification Process is also environmentally safe for toxicity leaching. The verified glass can be used for the construction work. The reaction processes in the gasifier produce mainly syngas (Hydrogen and Carbon monoxide). The PGP out-put gas is environmentally safe. Plasma Gasification technology and its plasma torch system when compared to incineration or traditional gasification offer unique environmental benefits.

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