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RESEARCH ARTICLE

PLASMA TECHNOLOGY AS WASTE TO ENERGY: A REVIEW

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Abstract

The age of urbanization has brought exponential growth in population and development along with the huge amount of waste generation. The waste generated is a mix type of waste which is difficult to manage using conventional methods and is ever increasing and changing in nature, blocking essential space that has become an expensive commodity in today's world. Conventional techniques such as combustion, land filling incineration, gasification have been the conventionally preferred method of waste management. The paper proposes a critical assessment of traditional waste to energy (WtE) procedure, starting from basic aspects of the process, performance, environmental assessment parameters to plasma gasification, a alternate WtE. This will assess the socio-aspect of plasma gasification , a more sustainable waste management system with producing a synthetic gas as by-product and slag. Although plasma has high installation and maintance costs, revenue generation form product can make it financially viable. This paper discusses the current limitations of this technology and highlights a few studies that are being conducted around the world that may soon take this concept from technical feasibility to practical reality.

Introduction:-

One of the most pressing problems facing municipalities is efficient sustainable and long term disposal of urban solid waste. Waste problems in cities include the increasing difficulty of acquiring new land areas for disposal, the generation of pollution from processing and disposal of waste, disposal caused resource depletion and the huge cost involved in waste processing. Uncontrolled dumping of wastes on outskirts of town and cities has created overflowing landfills, which are not only very difficult to reclaim because of haphazard manner of dumping, but also have serious environmental implications in terms of water contamination, land degradation and air pollution contributing to global warming. Environmental degradation is taking place and organizations that are responsible for environmental management are facing many problems and challenges.

With the technological advancement and invention of new products and services, the quantity and quality of the waste have changed over the years. Waste characteristics depend on income, culture and geography and also on a society's economy and, situations like disasters that affect that economy. The management of different waste requires different kind of procedures to handle as the different toxic compounds that might be present in one may

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not be present in the other [2,4,17]. The large amount of waste produced due to increase in utilities as well as population and goes to landfill space or buried beneath the ground. The problem of landfill space bound to get worse day by day. The 5R solution - Recycling, Reduce, Reuse, Refuse, Recover, Residual Management are suggested to cater such waste management problems [5,17.18]. Recycle is one of the option which our Mother Nature do.Recycles all types of waste materials that are made from multiple materials that cannot be easily broken down and turned into new things. The organic content of the MSW varies between 35–60% in different parts of the country[1].

The compost and waste to energy facilities are facing problems simply because of poor quality of segregation and therefore, poor quality of end product that has no market demand. The various traditional methods like combustion, biodigradation has need used for recycle, in utilizing all natural ways of handling the waste in a nature or eco friendly manner. Open dumping has been considered the most accepted practice of solid waste disposal. On an average, 5–6% of the wastes are disposed of by using various composting methods Another possibility is to incinerate waste, and energy can be produced by using it as a fuel but incinerators are deeply unpopular with local communities because of the air pollution they can produce. A new type of waste treatment technology called plasma arc recycling (sometimes referred to as "plasma recycling," "plasma gasification," "gas plasma waste treatment," "plasma waste recycling,"etc.) aims to change all this. The waste is heated at super-high temperatures to produce gas that can be burnt for energy and rocky solid waste that can be used for various purposes. It is an environmental friendly technology for waste treatment [3].

Country/Territory	Disposal methods			
	Land disposal (per cent)	Incineration (per cent)	Composting (per cent)	Others (per cent)
Australia	96	1	-	3
Bangladesh	95	-	-	5
Brunei Darussalam	90	-	-	10
Hong Kong	92	8	-	0
India	70	-	20	10
Indonesia	80	5	10	5
Japan	22	74	0.1	3.9
Republic of Korea	90	-		10
Malaysia	70	5	10	15
Philippines	85	-	10	5
Singapore	35	65	-	-
Sri Lanka	90	-	-	10
Thailand	80	5	10	5

Source: State of the Environment in Asia and the Pacific,.(UN), United Nations. NY : United Nations Publication, 2000

Traditional Waste Management Methods:

Rapid advancement in the field of mining and real estate aroused the need of land filling .Proving its worth land filling has emerged as one of the cheapest and easiest method of SWM burn out mines and low level areas are target areas of dumping solid waste thus levelling the ground for useful purpose.This method suffers from the disadvantage of releasing poisonous gases like methane causing deterioration of environment. The various thermochemical treatment processes like composting, incineration, pyrolysis etc are an essential component of a sustainable integrated municipal solid waste (MSW) management system [5,9].

The Composting, a biological decomposition of organic waste like food or plant material by bacteria, fungi, worms and other organisms under controlled aerobic conditions (occurring in the presence of oxygen), and Incineration, Incineration is a waste treatment method that involves the combustion of organic substances contained in waste materials into ash, flue gas, and heat [6,10]. It is characterized by higher temperature and conversion rate than other technologies, biochemical and physicochemical, processes, so allowing an efficient treatment of different types of solid waste, in particular of unsorted residual waste (i.e. the waste left out from separate collection, which cannot be conveniently recycled from an environmental and economic point of view). Their main advantages are: strong reduction of the waste in mass (about 70–80%) and in volume (about 80– 90%), a drastic saving of land . The destruction of organic contaminants, such as halogenated hydrocarbons, concentration and immobilization of inorganic contaminants, utilization of recyclables from the thermal residues, such as ferrous and non-ferrous metals from bottom ash and slag and reduction of greenhouse gas emissions from anaerobic decomposition of the organic wastes are few features of these technologies. Thermal treatment plants can convert the energy value of MSW into different forms of energy, such as electricity and process heat for both utilization in industrial facilities or district heating [7,12]. They utilize one or more of the three main thermochemical conversion processes of combustion, pyrolysis and gasification. Unlike incineration, gasification do not produce energy from waste through direct combustion [24]. Waste, steam, and oxygen are fed into a gasifier in which heat and pressure break apart the chemical bonds of the waste to form the synthesis gas (syn gas). It allows the breakdown of hydrocarbons (HCs) into the gaseous mixture by carefully controlling the amount of oxygen available. Syn gas may be used directly in internal combustion engines or to make products which are substitute for natural gas, chemicals, fertilisers, transportation fuels and hydrogen. Pollutants are removed from syngas before it is combusted, so that it does not produce the high levels of emissions associated with other combustion technologies. Like gasification, pyrolysis also converts waste into by heating under controlled conditions, but involves thermal degradation in the complete absence of air. Pyrolysis typically occurs under pressure and at operating temperatures above 430ºC (800ºF). Pyrolysis produces char, pyrolysis oil, and syngas, all of which can be used as fuels. Gasification and pyrolysis are extremely efficient methods of using biomass to produce energy, both being more efficient than incineration. They are flexible technologies in which existing gas-fuelled devices (ovens, furnaces, boilers, etc.) can be retrofitted with gasifiers and syngas can directly replace fossil fuels. Gasification is able to generate energy at a cheaper rate and more efficient than the steam process used in incineration[15].

The various study has been done on tradition waste management methods based on cost of the technology, environmental impact assessment, life cycle etc. The performance is based on their geographical location, size and input waste type [2,14]. All the traditional technologies have a drawback of waste generated, time required and ash content produced so there is a need of technological advancement in this field which can overcome all these limitations.

Plasma Technology:

Plasma is the ionized state of matter, it is confirmed by a quasi-neutral gas composed of charged and neutral particles, which exhibits a collective behavior; plasma is the most abundant form of matter in the universe. It is formed whenever ordinary matter is heated over few thousand degree C, which results in electrically charged gases or fluids. They are significantly impacted by the electrical communications of the particles and electrons by the presence of an attractive field. The plasma VI characteristic is similar to an electrical discharge tube [12,31]. A high nonlinear Voltage-Current curve of current I is observed on raising the voltage V as shown in fig . It can be easily categorized in The three major regimes : Dark Discharge, the Glow Discharge and the Arc Discharge. The application of high current density is enough to heat the cathode to incandescence, then a discontinuous glow-to-arc transition region appears. The arc regime is comprised of three regions: the glow to arc transition, the non-thermal arcs, and the thermal arcs. Thermal arcs are formed at higher pressures and higher gas temperatures than non-thermal arcs; however, non-thermal arcs may exist at atmospheric pressure. The electron density in thermal arcs is higher than in non-thermal arcs. In non-thermal arcs, low emission arcs require thermionic emissions from cathodes, whereas in thermal arcs, high intensity arcs usually operate in field emissions [7].

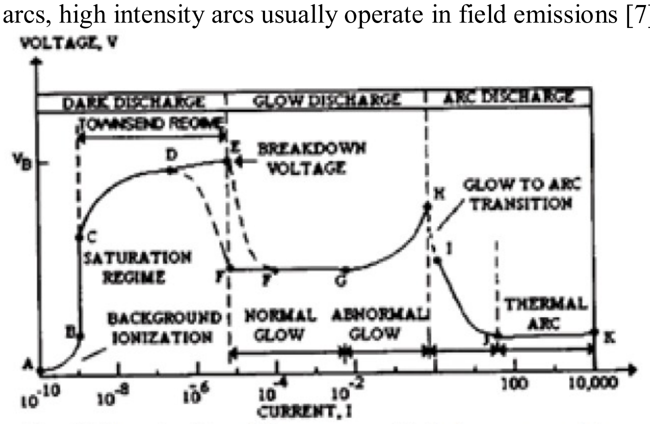


Fig : VI Characterstic of low presuure DC discharge vaccum tube

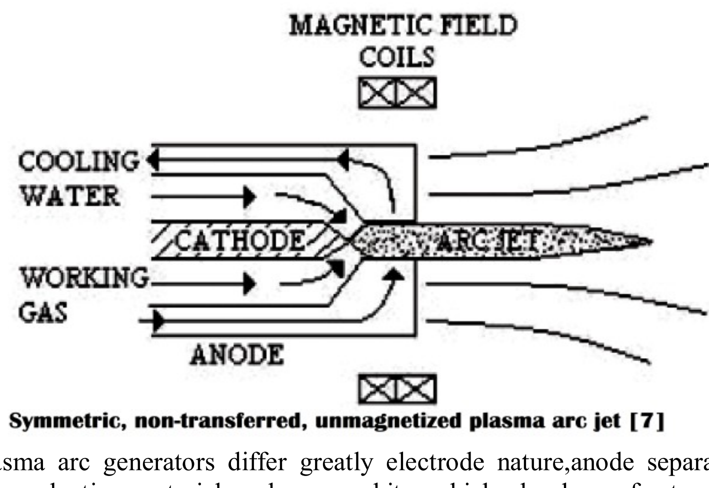
The fundamental concept of plasma generation is similar to vacuum tube DC electrical discharge, here a huge amounts of electrical energy are provided to a gas at certain temperature and pressure, it tends to excite and ionise it, generating electrons that further collide with consequent atoms in-elastically thereby generating more ions and electrons [22]. This process continues in a self-sustaining manner, provided a steady source of energy is continually applied with thermodynamic equilibrium. A significant electrical resistivity is generated across the system due to high temperature. Plasma is created through the application of energy sourced from electric discharges of frequencies ranging from Direct Current (DC) to the optical range which is in the order of 10^{15}. The energy absorbed by the electrons is spent in excitation of atoms and molecules, nonelastic collisions for ionisation and for elastic collisions for direct gas heating [7,23]. This spent energy is subsequently dissipated into the environment. Plasma is created through the application of energy sourced from electric discharges of frequencies ranging from Direct Current (DC) to the optical range which is in the order of 10^{15}. Plasma can be categorized into three types, thermal plasma, cold plasma and warm (intermediate) plasma.

Thermal plasma :
It is a type of plasma like fusion plasma that is commonly found in stars with a temperature range of 4000 K to 20,000 K. it is achieve only if the energy transfer from the electrons to gas heating occurs fast and thereby attaining thermal equilibrium. Thermal equilibrium infers that all the species of the plasma, such as electrons, atoms, ions and neutral species, all retain the same temperature.

Cold plasma:
The second type of plasma, or the cold plasma is another example of non-equilibrium plasma, with low energy levels as the energy transfer from electrons into gas heating is very slow. The energy level is low enough for the molecules of the plasma to rapidly cool upto the surrounding temperatures. Corona discharges, whether AC, DC or pulsed, are capable of producing this kind of plasma, at atmospheric pressure.3

Warm Plasma:
The third type of plasma, warm plasma has high translational temperatures of around 2000 K, although it is significantly lower than thermal plasmas. This plasma dissipates energy into the atmosphere through non-equilibrium discharges. Microwave plasmas are one such type of plasma with physical properties that allow for a stable condition to generate, under a range of external parameters.

Thermal plasma can be generated by various methods of discharges[7,15] , but most commonly used are arc generated plasma and Radio Frequency inductively coupled discharges .In Arc generated plasma , high Direct Current used across two electrodes to create a potential difference across the input gas. The gas is forced to pass through the limited space between the two electrodes which provides the energy required, beginning the electrical breakdown that leads to plasma generation. The plasma leaves the torch through a circular opening in one of the electrodes, usually the anode (non-transferred arc generators). The plasma arc that produced is unstable. Therefore, an external magnetic field is used to stabilise the arc. The stabilisation of the arc can also be done by limiting the flow rate of the plasma gas.



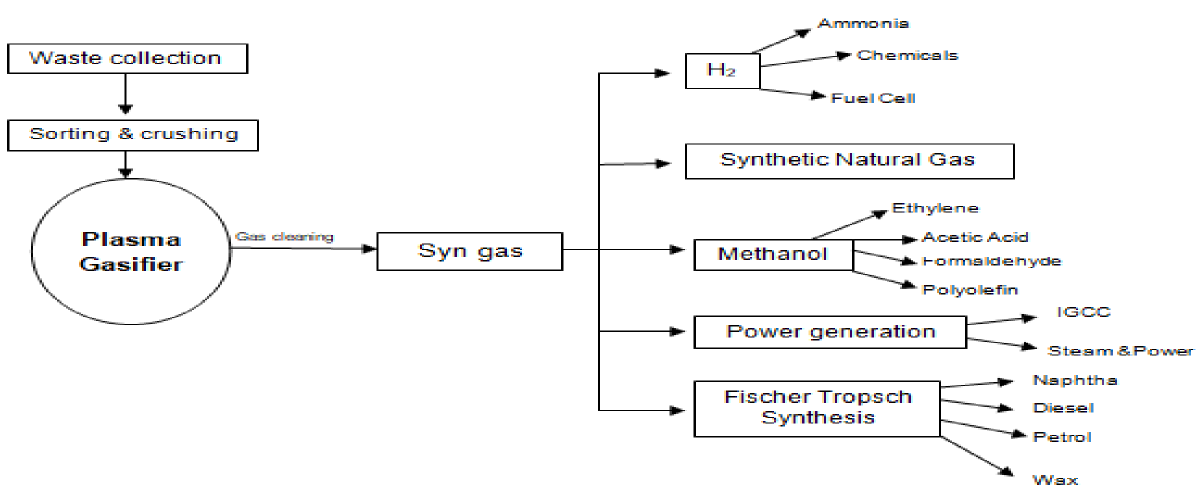
Symmetric, non-transferred, unmagnetized plasma arc jet [7]

The designs of DC plasma arc generators differ greatly electrode nature,anode separation with respect to the cathode. It is usually a conducting material such as graphite, which also has refractory properties and does not require to be water cooled. It can have a hole through it which will allow the plasma gas to pass through or the gas could be made to pass through the cathode externally, guided by a constrained wall. Transferred arc reactors may utilise multiple rod electrodes to generate a plasma arc. Non-transferred DC arc torches are used popularly for their high temperature plasma arcs and better mixing of the reactants with plasma. . One of the major drawback with DC thermal plasma arc generators is a phenomenon called sputtering where the discharged ions and atoms from the plasma gas collide with cathode surface causing the release of secondary electrons and some atoms from the cathode which later either settles along the circular anode surface or passes through the opening, along with the arc and contaminates the reactants. Due to this phenomenon the cathodes have a definite life span and require time-bound replacements which increase maintenance cost and frequency of maintenance. In addition, more than 50% of electrical energy fed into thermal plasma is wasted through cooling water which is necessary for stable arc operation. Otherwise, metallic electrodes are readily corroded or melted. This is the major drawback that results in the energy efficiency of thermal plasma to be poor. In case of an RF inductively coupled discharges of thermal plasma, which is being increasingly considered as their design prevents any contact between the plasma gas and the electrodes, the energy necessary to generate the plasma is provided by the RF induction coils and allows the feed to be injected directly through the plasma region.

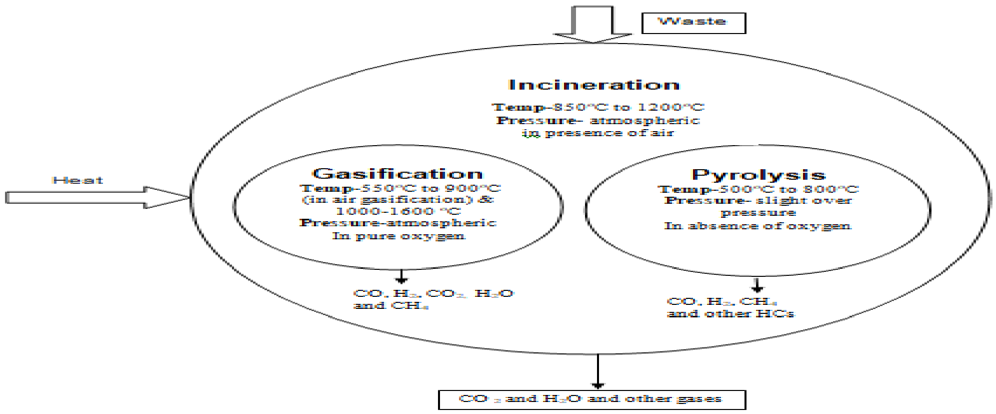
Plasma Technology for MSW:

The thermal plasma has most feasible solution to the impending and escalating waste management crisis from household waste to other hazardous wastes such as medical wastes. Thermal plasma treatment is based on their high temperature, intense and nonionising radiation nature. The energy density of the plasma arc is higher than a conventional combustion flame with flexibility in processing a wide range of Waste forms from regular solid MSWs, liquid such as urine to poisonous gases. The high temperature with high energy density of thermal plasma, can accommodate a large throughput within a small scale waste treatment reactor. The steep thermal gradient of plasma that exists in these reactors allows for quenching process which is beneficial when trying to recover products from wastes. The high flux density generated by the plasma at the reactor boundary lead to a rapid attainment of steady state condition, effectively reducing the start-up and shutdown times. The reactors do not require any oxidants to produce the heat source and a very small volume of gas is produced which makes the entire process much more manageable. It is also cost effective as well as environmentally friendly as the emissions of greenhouse gases are much lower than accepted levels.

He plasma for MSW is effective in two forms. - Plasma pyrolysis and Plasma gasification. Plasma gasification refers to a range of techniques that utilize plasma torches or plasma arcs to produce very high temperatures that are particularly effective for highly efficient gasification. Plasma pyrolysis is the decomposition of any given feed by gasification in an oxygen starved environment whereas plasma gasification involves the addition of limited amounts of oxygen and steam. In both processes plasma is the sole source of heat and No combustion takes place. The products from conventional gasification units are similar to those from generated in plasma gasification/pyrolysis, however the syngas produced from plasma gasification/pyrolysis is cleaner, devoid of huge quantities of soot.



According to a study by A. Gutsol [7] Solid waste contains organic content, metallic particles, inorganic contents and majority of them is organic. The plasma arc in a waste treatment facility heats the waste to temperatures anywhere from about 1000–15,000°C (1800–27,000°F), but typically in the middle of that range, melting the waste and then turning it into vapor. Simple organic (carbon-based) materials cool back into relatively clean gases; metals and other inorganic wastes fuse together and cool back into solids.

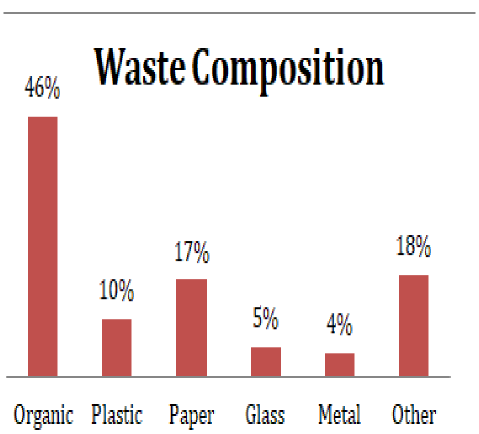


The end result of plasma gasification is the production of synthetic gas (syn gas), composed pre-dominantly of carbon monoxide and hydrogen, although certain percentage of carbon dioxide and hydrochloric acid are also present, along with vitrified slag which contains molten form of all the inorganic components such as metal scrap present in the MSW feed along with any residual toxic components in inert form. The syn gas can be piped away and burnt to make energy (some of which can be used as fuel for the plasma arc equipment), while the "vitrified" (glass-like) rocky solid can be used as aggregate (for road building and other construction). In practice, the syn gas may be contaminated with toxic gases such as dioxins that have to be scrubbed out and disposed of somehow, while the rocky solid may also contain some contaminated material[7,12]. Depending on the regional economics, syn gas can be used for electrical power, methanol or liquid fuels such as jet fuel, diesel, synthetic natural gas generation and others. Plasma gasification is not to be confused with incineration, which is the burning of waste-emitting greenhouse gases and creating ash. It is also different from gasification, as gasification process has many installations today creating syn gas to produce polymers for the plastics industry. Plasma gasification used for MSW would require no sorting of materials, eliminate the need for landfills, remove traffic of trucks from our roads and be financially viable. The major advantage of using pyrolysis process is that the metallic particles do not evaporate as in the case of combustion where oxygen is employed which forms metal oxide which is fatal to further proceeding of the process[15]. Due to pyrolysis, thermal cracking may take place which can convert metallic parts into vitreous form which is collected by density difference method into useful by-products.

Plasma gasification is a thermo-chemical process and the plasma furnace is the central part of the process within which several chemical conversions take place that can be defined byfollowing energy conversion formulas[22-33]:

$C(s) + H_2O = CO + H_2$ [heterogeneous water gas shift reaction —endothermic]
$C(s) + CO_2 = 2CO$ [Boudouard equilibrium—endothermic]
$C(s) + 2H_2 = CH_4$ [hydrogenation gasification—exothermic]
$CH_4 + H_2O = CO + 3H_2$ [methane decomposition—endothermic]
$CO + H_2O = CO_2 + H_2$ [water gas shift reaction—exothermic].

In plasma gasification, feedstock (trash) is introduced into a vessel of extremely high heat (~2,000 deg F) capable of breaking all organic chemical bond and reducing all trash including plastic, paper, glass, yard waste, food, filth, etc. to basic elements. The heat also melts metals, which are recovered.



WtE Technology Comparison:
The various waste to energy (WtE) methodologies has developed from combustion, gasification, incineration to plasma technology[18,21]. All WtE itself requiring extra material and energetic resources and waste as a resource and help decline in waste generated per capita in absolute term[12]. Recycling and re-using waste are economically attractive options due to the widespread

collection because major portion of waste management budget is being utilized in collection and transportation of the waste[12,16]. These utilization set waste as resources and help as a key to circular economy. Thus, parameters such as the investment, the return period and the monetary revenue constitute challenges to overcome so as to implement this environmentally favorable technique.

The composting and combustion are one of the oldest methods for waste treatment but limited to organic waste like food / plant material. With rapid growth of industrialization

land filling has emerged as one of the cheapest way to dump waste but suffer from the disadvantage of environment deterioration and space problem. The advancement of science developed new technology like gasification, incineration, pyralosis etc. These are thermal conversion methodologies with the advantage of producing residual amounts of sub-products like ash and gaseous emissions [18,24]. These help in prevention of hazardous emissions such as NOx, SOx etc. Such heating produces a synthetic gaseous stream (syngas), which can subsequently be used to produce a diversity of commodities such as fuels, electricity and chemicals. The efficiency to reduce environmental harm of such methodologies depends on various factor such as input materials, temperature, pressure and chemical value of the treated waste. More friendly methods are developed day-by-day, plasma gasification constituting a suitable alternative, since it combines the advantages of regular thermal conversion methodologies with a high-performance syngas cleaning step. This not only reduces gaseous emissions but also provide economic value product. The details of such technologies has been shown as :

	Parameters	Incineration	Gasification	Pyrolysis	Plasma gasification
Operating Parameters	Process	To maximize waste conversion to high temperature flue gases mainly CO_2 and H_2O	To maximize waste conversion to high heating value flue gases mainly CO, H_2 and CH_4	To maximize thermal decomposition of solid waste to gases and condensed phases	To maximize waste conversion to high temperature flue gases
	Operating Condition	Oxidizing(oxidant amount larger that required by stoichiometric combustion) In presence of Air Between 850°C and 1200°C under atmospheric pressure	Reducing(oxidant amount lower that required by stoichiometric combustion) Air, pure oxygen, oxygen enriched air, steam Between 550°C and 900°C(in air gasisfication) and 1000-1600 °C under atmospheric pressure	Total absence of any oxidant Between 500°C and 800°C slightly over pressure	Oxidizing Very high temperature(1500 to 5500°C) under atmospheric pressure
Environmental impact	Mass reduction (wt%)	75	82	84	90
	Residue(ton/ton MSW)	0.22(ash)	0.2(ash)	0.21(ash)	0.18(ash)
	Ash disposal & production of vitrified slag	No	No	No	Yes
	Pollutant	SO_2, NO_2, HCl, PCDD/F, particulate	H_2S, HCl, COS,NH_3, HCN, tar, alkali, particulate	H_2S, HCl, NH_3, HCN, tar, particulate	-
	Gas cleaning	Treated in air pollution control units to meet the emission limits and then sent to the stack	It is possible to clean the syn gas to meet the standards of chemicals production processes or those of high efficiency energy conversion devices	It is possible to clean the syn gas to meet the standards of chemicals production processes or those of high efficiency energy conversion devices	It is possible to clean the syn gas to meet the standards of chemicals production processes or those of high efficiency energy conversion devices
Cost	Installation	Very high	Moderate	Moderate	High
	Operational & maintenance cost	High	Moderate	Moderate	Very high
	Plant service life(year)	30	30	20	20
Processing capability	Wet waste handling	Limited	Limited	No	No
	Automation level	Moderate	Moderate	Moderate	High
	Waste sorting required	Yes	Yes	Yes	Yes
Energy	Power generation capacity(MW/ton of MSW)	5	5.5	5.5	5
	Net energy production potential(kWh/ton of MSW)	50	20	40	-

Plasma technology is going to be an effective and environmentally friendly technology for MSW disposal and waste-to-value processing. It can be used to recover energy from plastic solids, MSW, biomass as well as to treat hazardous waste form biomedical and industries [18,21]. Plasma gasification is comparable in terms of various performance parameters (e.g. cost, service life and processing capabilities, energy comparison, and environmental impact comparision given in table. Positive values mean harmful impacts (grieving natural resources or emission of contaminants), while negative values represent environmental credits or avoided burdens (emissions to the environmental compartments are prevented or resources are saved).

WtE Technology Comparison:

The various study claim Plasma gasification, a relatively expensive technology as compared to other technologies such as pyrolysis, and gasification for waste-to value conversion. The installation cost of plasma depends on factors like geographical location, plant capacity, waste composition and process parameters. Special materials are required for construction with refractory lining , and high level of automation to sustain higher temperatures which makes the technology expensive, the expense of plasma sources (e.g. plasma torch and plasma arc), and limited technical experts in the field due to it being a relatively new technology. Operational and maintenance costs of plasma gasification are also expensive[18,21]. It may be due to the fact that It operates with an expensive DC power supply which requires frequent maintenance. High amount of plasma energy is required to heat, melt and finally vaporise waste for molecular dissociation and breaking apart molecular bonds to separate complex molecules into individual atoms in gaseous phase. Improper sorted waste can adversely affect synthesis gas production and can damage plasma gasifier refractory linings. Proper segregation and sorting of waste is required before it reaches the facility otherwise it can severely reduce refractory service life by releasing highly reactive, hot chlorine gas.. Furthermore, wet waste affect the yield of synthesis gas adversely and requires more energy to process it, as compared to dry waste. The initial cost in the plasma technology cannot be reduced but operation and maintenance cost can reduced by generating revenue from the by products in the process[3,7,15]. The energy input can be reduced by supplying properly segregated waste. Properly segregated waste will also help in reducing maintenance cost. If waste is properly segregated, it will also help in production of good quality of Syn gas which can have good value in market [15,23,33]. The energy produced from syn gas can be used in operation of the plant. More homogenous, refuse-derived fuel with a lower fraction of non-combustible components is a desired plasma gasification feed as it produces products that are more volatile and maximise energy production. A desirable plasma gasification feed needs to contain a minimal metal and glass content as these components decrease the heating value of the refuse-derived fuel and can cause various operational problems [18,21,22,33].

	Incineration	Gasification	Plasma gasification
Total cost (Installation , Maintenance & staff)	69.99	139.42	58.62
Revenue	87.77	122.50	127.89
Net Result	17.78	−16.92	69.27

Percentage cost incurred in various technologies in MSWM			
	Plasma gasification (cost %)	Incineration (cost %)	Gasification (cost %)
Staff	3-5	3-4	1-2
Energy	12-15	10-12	4-5
O/M	70-75	25-30	80-90
Waste Management	9-10	55-60	4-5

MSW Plasma gasification will eliminate the need for landfills, remove long-haul trucking from our roads. The primary products from plasma gasification are: synthetic gas ("syn gas"), and slag/vitrified glassy rock. Both of these products have high value, with syngas being the primary product. Depending on the regional economics, syngas can be used for electrical power, methanol or liquid fuels such as jet fuel, diesel, synthetic natural gas generation and others. Syn gas can also be converted into high-value products such as highly pure hydrogen, fuels, and other valuable chemical compounds. Such revenue generation can make it financially viable. In view of landfills and other conventional waste treatment unit high capital investment, plasma gasification seems to be a good solution with project payback in few years. This creates a true circular economy!

The Plasma gasification technology is relatively new and people have limited awareness about the technology also people have various safety concerns about its extreme process conditions so it was rated at a moderate community readiness level (CRL)[18,21,22,32]. These observations may also be due to plasma gasification being a relatively new technology for waste-to-value processing and waste management, the current lack of standards and government regulations, a limited number of prototype units, and scepticism of environmental effects of the technology. From a practical point of view, it is necessary for plasma gasification to have higher levels of CRL and general public approval. Regardless of how sound its technical concept is, if the public is concerned about the technology then politicians, companies, or end-users will be less motivated towards the implementation of such a technology [22].Public readiness can be improved by spreading public awareness about waste to value technology [21,24]. Health equipments and kits can be developed for the operator to make it safe for health of the people working on the plant. Technology readiness levels (TRL) assessment examine a technology based on requirement, concept and capabilities on a scale of 0 to 9 with 9 being the most mature technology [3]. The plasma gasification technology is rated moderate to high as it partially achieved the first eight levels of TRL.

Table: Environmental impacts for the MSW thermal conversion, per functional unit.

	GWP (kg CO_2 eq.)
Incineration	−170.9
Gasification	27
Plasma gasification	−31

Conclusion:-

Science based solution of WtE has evaluated multiple approaches and concluded plasma gasification is the most effective technology to address the intractable problems facing our waste handling industry, it is a proven solution waste management. This is a proven technology used in other domains and parts of the world since the early 2000s. Reduction of initial capital costs of plasma gasification does not seem realistic; however, its operational costs can be targeted for reduction by generating revenue from synthesis gas and fuels produced from the process. Plasma gasification processing needs to be better understood, more detailed fundamental studies for generating fundamental data are required, and a process systems engineering approach needs to be used for aiding in process design and optimisation decisions.

The various WtE technologies analysis indicates that plasma is a technically viable option for the waste to energy conversion including residual. It will meet existing environments and emission limits and also have a remarkable effect on reduction of landfill disposal waste options.

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