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WASTE DISPOSAL &POWER GENERATION THROUGH THERMAL PLASMA PYROLYSIS

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ABSTRACT

Plasma pyrolysis converts organic waste into commercially useful by-products, thus reducing the problem of environmental wastes and power shortages at the same time it provides some useful syngas as well as energy. Medical waste is pyrolyzed into CO, H_2, and hydrocarbons when it comes in contact with the plasma-arc. Adoptions of advanced thermal conversion techniques such as thermal plasma technology are increased and are expected to become commercially viable in the near future. This paper outlines a comparative study of solar thermal pyrolysis and thermal plasma pyrolysis along with its use in safe decomposition of medical waste along with the recovery of energy. Moreover the development of thermal plasma for pyrolysis/gasification systems as energy recovery source has been discussed here.

Keywords: Thermal plasma pyrolysis/gasification, syngas.

I. INTRODUCTION

The phenomenal increase in the quantity of medical wastes generated in the hospitals, organic wastes e.g. rubber and plastic have become problematic therefore the use of appropriate technologies for safe disposal and recovery of resources as well as energy from them has become prime importance. Various researches have been made on plasma pyrolysis/gasification systems for treatment of waste and energy recovery[1]. Organic wastes have valuable potential as secondary raw material. Decarbonisation of fossil fuels and gaseous fuels liberates CO_2 during a transition period, intensity of which should be low. Hydrogen is the ultimate step and it is viewed as one of the most promising energy carriers to avoid CO_2 emissions. Natural gas, mainly composed of methane, make the transition from fossil fuel economy to hydrogen economy because it shows the highest H/C ratio among the different hydrocarbons.[2]Many technologies had been developed by the researchers for the recycling of the organic waste but mechanical recycling is most preferred, although the plastic waste should be homogeneous and uncontaminated. However, the incineration is the simplest and most effective method for energy recovery, although, heat recovery is not appropriate from entropic aspect. Thermal plasma technology, the area of researches for long time [3], has proved very useful to overcome the problem and is an alternative to the incineration. Although the most important application of thermal plasma wastes treatment is destruction of hazardous wastes [4] and recovery of energy. This technology is established in metallurgical processing and materials synthesis [5] etc. it is well known as plasma pyrolysis. It is an appropriate method for polymer pyrolysis. It also produces a gas with low tar content and high heating value, which can be applied well to gas turbines for power generation or used as a synthesis gas for hydrogen production [6]. When carbonaceous solids are injected into plasma, they are heated up very rapidly and give rise to CO, H_2, CH_4, C_2H_2 and other hydrocarbons. Thus by plasma processes carbonaceous solid can be converted into valuable gaseous fuels. Research has been done on plasma pyrolysis/gasification e.g. an inductivity coupled plasma technology was used for the depolymerisation of the polyethylene [7] and waste rubber was used as the raw material for production of syngas by thermal plasma pyrolysis [8]. Laboratory-scale capacitively coupled radio frequency (RF) plasma pyrolysis reactor was developed by Tang and Huang for wood and char gasification [6]. Experimental setup with block diagram and schematic representation has been previously discussed [3].

II. PLASMA PHYSICS

Plasma is the fourth state of matter. About 99% of the matter in the universe is in the plasma state. Plasmas exist in astronomical bodies with temperatures in millions of degrees. Plasma is a gas in which an important fraction of the atoms is *ionized*, so that the electrons and ions are separately free. This occurs when the temperature is hot enough to overcome ionization threshold energy, about 13.6eV.

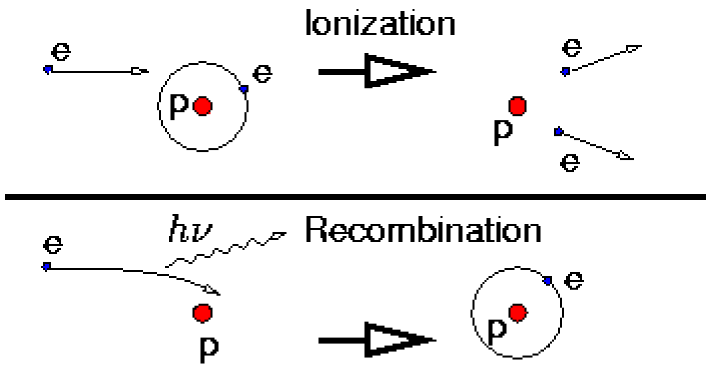

Fig 1:-Balance between collisional ionization and recombination.

The presence of a non-negligible number of charge carriers makes the plasma electrically conductive so that it responds strongly to electromagnetic fields [9].

Plasma physics applied to gasification represents a clean and efficient option to manage waste in an environmentally responsible manner. The plasma gasification technology is ideally suited to process wastes such as Municipal Solid Waste (MSW), common hazardous waste, industrial waste, chemical waste, sediment sludge and biomass. Converting waste into various energy outputs reduces reliance on the use of conventional fossil based fuels by using readily available waste [10].

Thermal Plasma Pyrolysis- Thermal plasma pyrolysis is the process of reacting a carbonaceous solid with limited amounts of oxygen at very high temperature to produce valuable gas (H_2, CO and gaseous hydrocarbons) and solid products (char). In the highly reactive plasma zone, there is a large fraction of electrons, ions and excited molecules together with the high energy radiation. When carbonaceous particles are injected into plasma, they are heated very rapidly giving rise to hydrogen and light hydrocarbons such as methane and acetylene. The process is as under:

- A very fast heating of the particles as a result of their heat exchange with the plasma jet.
- An explosive liberation of volatile matter from the particles.

- A very quick gasification of the homogeneous phase and rapid heat and mass exchange. This process may be replaced by quench technology in order to achieve a certain monomer.
- Further gasification of char particles with various gaseous components. Addition of water/ steam promotes the syngas (H_2, CO) production.
- Syngas is a mixture of hydrogen and carbon monoxide and it can be converted into fuels such as hydrogen, natural gas or ethanol.

III. PLASMA GASIFICATION PROCESS

Plasma gasification is an efficient and environmentally responsible form of thermal treatment [11] of wastes which occurs in oxygen starved environment so that waste is gasified, not incinerated. Westinghouse Plasma Corporation (WPC) has developed a plasma gasification system [12], [13], [14] which uses plasma heat in a vertical shaft cupola adopted from the foundry industry. The plasma gasification process is illustrated in Fig. 2 below. The heart of the process is the ―Plasma Gasifier; a vertical refractory lined vessel into which the feed material is introduced near the top along with metallurgical coke and limestone. Plasma torches are located near the bottom of the vessel and direct the high temperature process gas into a bed of coke at the bottom of the vessel. Air or oxygen is introduced through tuyres located above the torches. The high temperature process gas introduced through the torch raises the temperature of the coke bed to a very high level to provide a heat reservoir and the process gas moves upward through the gasifying vessel to gasify the waste. The power of plasma gasification makes it environmentally clean technique. Plasma Gasification Plant projects [15] are being developed by many gas plasma companies, with real benefits obtained from this technology. Additional heat is introduced from the reaction of the carbon in the waste with the oxygen introduced through the tuyres to produce carbon monoxide in the gasification process. The hot product gas, passing upward though the wastes, breaks down organic compounds and dries the wastes at the top of the ―gasifier. As the waste moves downward through the ―gasifying vessel, inorganic materials such as metal, glass and soil are melted and produce a two phase liquid stream consisting of metals and a glass-like (vitrified) residue that flows to the bottom of the vessel. Discharge of the molten material into water results in the formation of metal nodules and a coarse sand-like material.

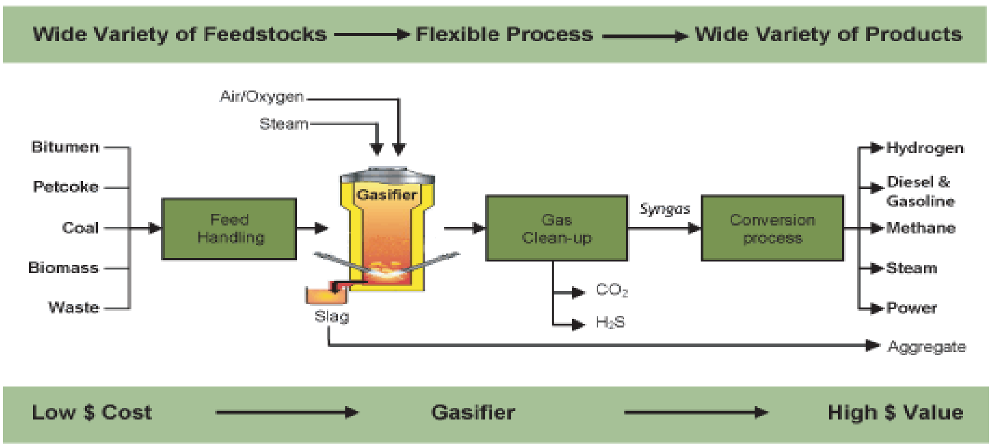

Fig. 2 Plasma gasification process

IV. CHEMICAL REACTION INVOLVED IN GASIFICATION PROCESS

The gasification reaction for MSW is generally written as follows [16]:

CHxOy + wH2O + mO2 + 3.76mN2 → aH2 + bCO + cCO2 + dH2O + eCH4 + fN2 + gC

Where waste material is described by its global analysis, CHxOy), w is the amount of water per mole of waste material, m is the amount of O2 per mole of waste, a, b, c, d, e, f and g are the coefficients of the gaseous products and soot (all stoichiometric coefficients in moles).

Table 1 Main chemical reactions of gasification[17]:-

Reaction name	Chemical reaction	Reaction enthalpy ▲*H*[1]
(1) Hydrogasification	$C + 2H_2 \rightarrow CH_4$	-74.87 kJ.mol-1
(2) Methanation	$CO + 3H_2 \rightarrow CH_4 + H_2O$	-206.23 kJ.mol-1
(3) Water-gas reaction	$C + H_2O \rightarrow CO + H_2$	+131.2 kJ.mol-1
(4) Carbon monoxide oxidation	$CO + ½ O_2 \rightarrow CO_2$	-283.01 kJ.mol-1
(5) Hydrogen oxidation	$H_2 + ½ O_2 \rightarrow H_2O$	-241.09 kJ.mol-1
(6) Water-gas shift reaction	$CO + H_2O \rightarrow CO_2 + H_2$	-41.18 kJ.mol-1

T = 298 K, P = 1.013 105 Pa, carbon as solid and water in vapour form.

Power Generation: Integrated Gasification and Combined Cycle (IGCC) For Power generation process, the product gas would be cooled prior to clean-up by passing through a heat recovery steam generator (HRSG) and the recovered heat used to generate steam. The cool gas would then be cleaned using readily available technologies, compressed, and used as fuel in a combustion turbine driving an electric generator. The hot turbine exhaust gas would pass through a second HRSG to produce additional steam prior to passing through a final emission control system designed to remove trace organics, metals and particulates prior to emission to the atmosphere. The steam from both HRSG units would be combined and used to produce additional electricity using a steam turbine generator. This is the process of integrated gasification combined cycle power generation.

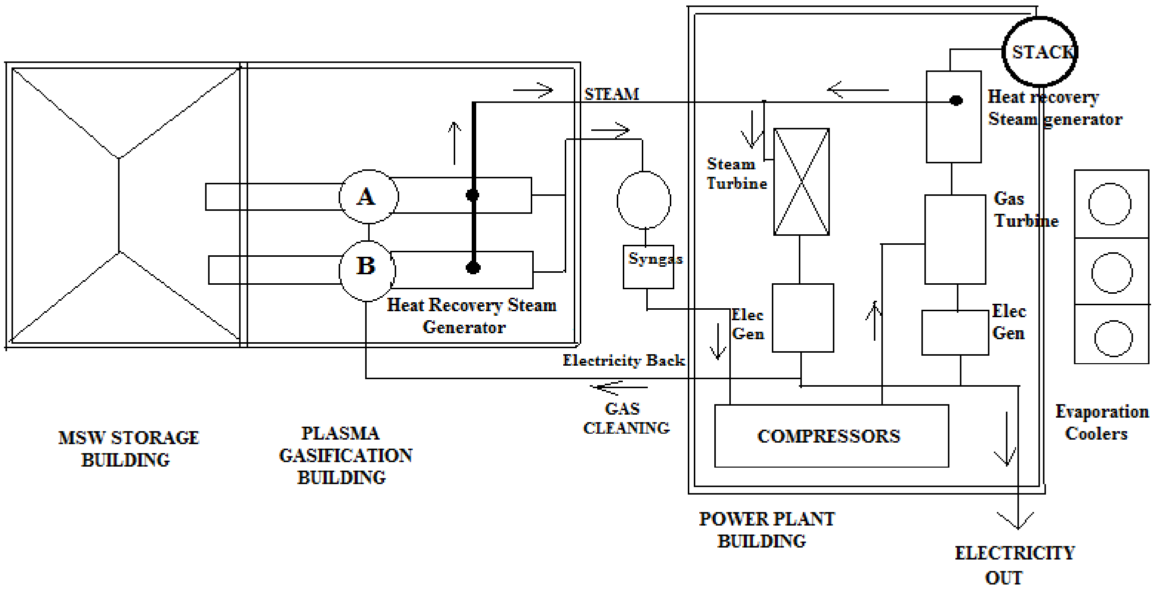

Fig 3MSW plasma plant using ICCG for power generation.

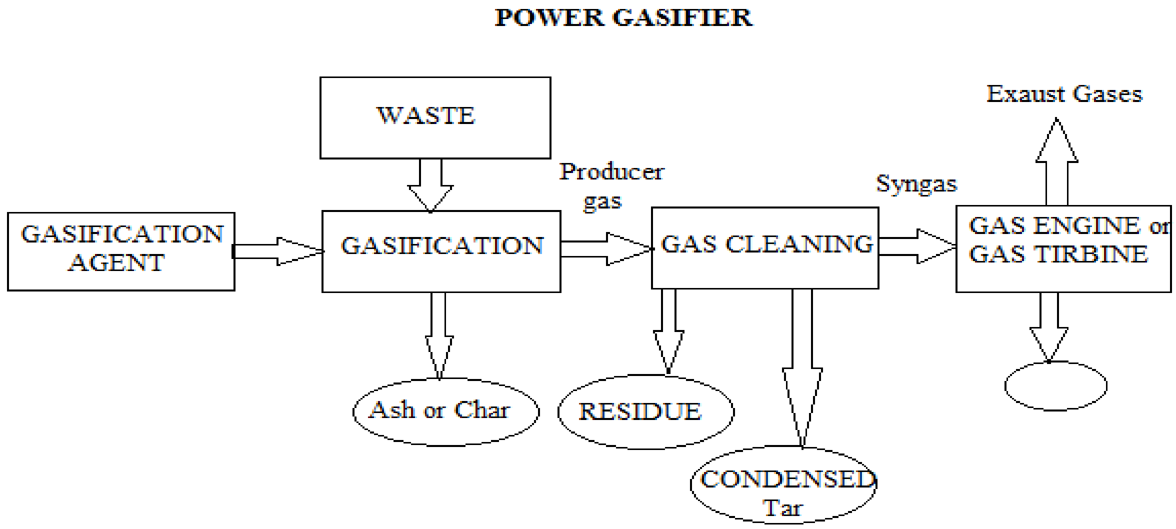

Fig 4 Block Diagram for Power Generation through Plasma Pyrolysis of MSW

Table: 2Comparison between conventional steam turbine and IGCC

		CONVENTIONAL STEAM TURBINES					COMBINED CYCLE (IGCC)				
HEAT CAPACITY MT/day	HEAT INPUT (MWh)	GROSS (Mwe)	Net (Mwe)	PLANT LOAD	MWh/ MT MSW	OVERALL EFFICIENCY (%)	GROSS Mwe	Net Mwe	Plant load	MWh/ MT MSW	OVERALL EFFICENCY (%)
500	83.3	19.7	16.1	3.63	0.77	19.3	33.7	26.7	6.93	1.28	32.1
2500	416.4	122.0	103.7	18.26	1.00	24.9	186.9	152.1	34.76	1.46	36.5
5000	832.7	259.6	223.1	36.52	1.07	26.8	393.4	323.8	69.52	1.55	38.9

Table 2 shows the comparison between conventional steam turbine and IGCC which indicates clearly that power generating efficiency from waste is high in IGCC as compared to conventional steam turbine.

Thermal plasma pyrolysis/gasification reactor systems- Researchers have been using various plasma reactors in past. Fixed and moving bed reactor type is used widely, while entrained-flow reactor and plasma spouted/fluid bed reactor type are also used by some researchers. These reactors are explained below and a comparison is made between various types of thermal plasma pyrolysis/gasification reactors as well as solar pyrolysis explained above.

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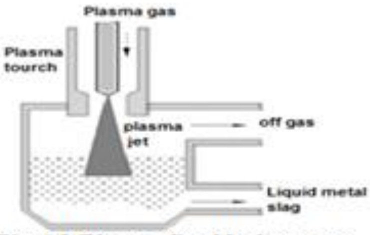

Fig 4.1 Plasma fixed bed reactor

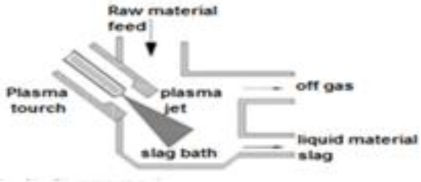

Fig 4.2: Plasma moving bed reactor

i) Plasma fixed/moving bed reactor: Plasma fixed and moving bed reactor has a bed of solid waste particles with a solid waste feeding unit, an ash-removal unit and a gas exit. For plasma fixed bed reactor, the waste enters from the opening at the centre of the reactor, while for plasma moving bed reactor, the waste enters the reactor through a point at the top or the side of the reactor (continuous waste feed mode, as shown in fig. 4.1 and 4.2 respectively). In the presence of plasma, the metals and ash form a liquid pool at the bottom of the reactor. The organic gas exits from the top of the reactor. These reactors transfers heat to the waste more efficiently resulting more complete waste conversion. Both approaches have been applied to small scale municipal solid waste or medical waste processing units [18]. The plasma gasification plant in Japan , process approximately 300 tons per day. This plant generates upto 7.9 megawatt-hour of electricity.

ii)Plasma entrained-flow bed reactor-Entrained-flow bed reactor is shown in fig. 3, in which the powder under treatment is injected in the flame of the plasma jet. The main advantage of entrained-flow bed reactor is the rapid heating and quenching rate as well as the short residence time of solid in plasma. We get high temperature, ultra-short contact time reactions and the intermediates as the desired products. Plasma entrained-flow bed reactor is used for producing acetylene i.e., a new route to synthesize chemicals from a clean coal utilization process and cracking of polymers e.g. poly-propylene to monomer propylene. This reactor is useful for the coal pyrolysis in thermal plasma for acetylene production. This process not only gives acetylene but also some valuable carbon materials and ethylene, methane, hydrogen and carbon monoxide as secondary products. Since the complex reaction process is operated at very high severity conditions, e.g., reaction temperature at 1500 K-3000K, high gas velocity and residence time in milliseconds, the reactor design meets great challenges such as the nozzle design for coal injection into the hot hydrogen stream, severe coking problems which prohibit the continuous operation, etc. In recent years, researchers use this reactor for waste treatment [19,20,21,22,23]. To study the degree of pyrolysis at different times and to analyse different product in different stage of a plasma pyrolysis process, an arc plasma entrained-flow reactor was developed, in which arc plasma generator was located at the upper part of the reactor apparatus and the solid material injector was located below the arc plasma generator. Solid powders from a screw feeder were injected using carrier gas (argon) into the plasma jet zone. The reacting plasma jet/biomass mixture then entered an extended reaction zone. Different samples at different positions of the reaction cavity were taken and it was found that major components in gaseous product were H_2, CO, C_2H_2 and CH_4. Maximum of 79% of carbon conversion and 72% of oxygen conversion was

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achieved. The specific power consumption in this experimental plasma apparatus under optimum conditions was estimated to be 3.7 kW h/Nm^3. However, its major disadvantages are its low energy efficiency.

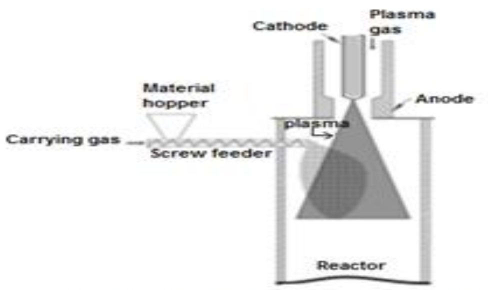

Fig 5: Plasma entrained flow bed

iii)Plasma spout/spout-fluid bed reactor-Plasma spout bed as shown in Fig. 6, where DC plasma jet forms the spout which provides heat for the process. Plasma spout bed provides higher operating temperatures, thus further reducing residence time. It was found that plasma spouted bed gave high degrees of conversion with short residence times but bed stability remains a problem. Fig 7 shows the plasma spout-fluid bed reactor, which is formed by combination of the plasma flow of the single central opening with the auxiliary fluid flow through the distributor plate (fluidized bed). This reactor overcomes the limitations of spout bed by providing the higher mixing rate, better solid fluid contact and improved mass and heat transfer characteristics. In past researchers have studied and reported methane pyrolysis [24] using R.F plasma generator which was located below the fluidization distributer of beds composed of sand, zirconia and graphite. Maximum acetylene conversion of 50% was achieved with methane and graphite particles fluidized bed.

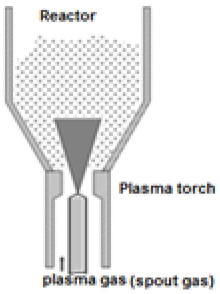

Fig 6: Plasma spot bed

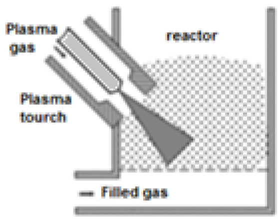

Fig 7:Plasma fluid bed reactor

Solar thermal methane decomposition

Experimental setup-The figure below shows the 10 kW solar reactor [25,26]. A graphite cavity receiver serves as a black body solar absorber of cubic shape (20 mm). Solar radiations enter the reactor through opening in the side equipped with a domed quartz window. Independent tubular vertical zones are inserted in the graphite cavity to carry out the reaction. Each reaction zone is fed independently by a mixture of Ar-CH_4. The reactants are fed in the innermost tube whereas the products are evacuated by the annular space between the two tubes; this design enables a preheating of the reactants by the hot products. Conduction losses are lowered due to the three different insulating layers first layer of carbon felt, intermediate refractory ceramic fibres, and outer layer of a highly efficient micro porous insulator with the total thickness of 150 mm. The 1MW solar furnace is used which can use up to 63 sun tracking heliostats (45 m^2 per heliostat) to reflect direct solar radiation toward a parabolic concentrator (1830 m²). At the focal zone, it delivers 9000 suns (1 sun = 1kW/m2) for full power. The power can be controlled by limiting the number of heliostats and by using a shutter.

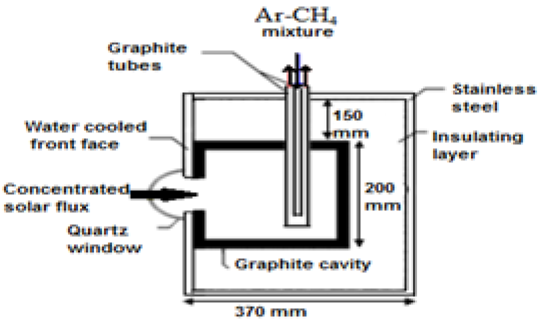

Fig 8: Cross section of 10 kw Solar reactor

Argon is fed in the tubes of the reactor until the targeted temperature is reached. Then a controlled mixture of argon and methane is fed in each tube with the help of mass flow meters. Pt-Rh thermocouple present in graphite cavity wall and solar blind optical pyrometer pointing towards the outer wall of a graphite tube inside the cavity through a CaF_2 window is used to measure the temperature. Exciting products are mixed together and cooled down with the help of a water cooled collector. The temperature of the gas-particle flow was about 373K and was directed towards the filter to separate the carbon particles. These gaseous particles are analysed by a continuous analyser and concentrations of H_2 and CH_4 are monitoring. A gas chromatograph is also used to measure the concentration of CH_4, C_2H_6, C_2H_4 and H_2.]

V. RESULTS AND CONCLUSION

Municipal Solid Waste Management is a great challenge to the Town Planners, 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 Wastel and/or ―Zero Land fillingǁ disposal methods. The Plasma Gasification Process of Municipal Solid Waste is a proven technology in which the weight is reduced by more than 88% and the volume of organic matter reduced by more than 95% [27].The vitrified glass generated as residue from Plasma Gasification Process is also environmentally safe for toxicity leaching. The vitrified glass contains mainly silica (sand, quartz), CaO, Fe_2O_3, and Al_2O_3 and can be used for the construction work. The fuel gas emissions are also within prescribed limit, the process is environmentally safe in terms of rate of Carbon dioxide emission [27]per MWH of electricity produced in comparison to different processes as depicted in Fig.3. The land requirement for management of Municipal Solid Waste in the City through landfills would be around 384ha for 1918MT/day. However, processing of 3000MT/day by plasma gasification process will require only 4.02ha of land. The sustainability of any solid waste management system depends [28] on numerous factors; however, the most important factor is the will of the people to change the existing system and develop something better. For any waste management to be successful, the government should take the required initiatives. Even though financial constraints are part of the system, the government can make a formal and sincere commitment for eliminating garbage from the City through a sustainable and environmentally responsible manner.

REFERENCES

[1] L.Tang,h.Huang, H. Hao and K. Zhao; Developement of plasma pyrolysis/gasification systems for energy efficient and environmentally sound waste disposal, Elsevier, Journal of Electroststics 71(2013)839-847.

[2] Shpilrain E.e., Shterenberg V.Y., Zaichenko V.M., "Comparative analysis of different natural gas pyrolysis methods", International Journal of Hydrogen Energy, 1999, 24, 7,

[3] Slapak MJP, Van Kasteren JMN, Drinkenburg AAH. Design of a process for steam gasification of PVC waste. Resour Conserve Recycling2000;**30**:81–93.

[4] Moustakas K, Fatta D, Malamis S, Haralambous K, Loizidou M. Demonstration plasma gasification/vitrification system foreffective hazardous waste treatment. *J Haz Mat* 2005;**123**:120–126.

[5] Pfender E. Thermal plasma processing in the nineties. *Pure Appl Chem* 1988;**60**:591–606.[6] Tang L, Huang H. Biomass gasification using inductively coupled RF plasma technology, *Fuel* 2005;84:2055–2063.

[7] Guddeti RR, Knight R, Grossmann ED. Depolymerization of polyethylene using induction-coupled plasma technology,*Plasma Chem Plasma Process* 2000;**20**:37–64.

[8] Puncocar M, Ruj B, Chatterjee P.K. Development of process for disposal of plastic waste using Plasma Pyrolysis technology and option for energy recovery. Elsvier SciVerse Science Direct 42 (2012) 420-430.

[9] Chen, Francis F. (1984), Plasma Physics and Controlled Fusion. Plenum Press. ISBN 0306413329.

[10] American Journal of Engineering Research (AJER)e-ISSN : 2320-0847 p-ISSN : 2320-0936 Volume-02, Issue-08, pp-65-75

[11] Nedcorp Group (2009) Environmentally Friendly Waste Destruction and Sustainable Renewable Energy. A feasibility document of Nedcorp group, July 2009.

[12] Evans Steve D, (2009), Plasma Gasification Plant Benefits for Municipal Waste Management, EzineArticles.com, available at http://www.articlesbase.com/literaturearticles/plasma-gasification-plant-benefits-for-municipal-waste-management-850915 . html, accessed during December 2011.

[13] Patel Munna Lal, Chauhan Janardan Singh (2012), Plasma Gasification: A Sustainable Solution for the Municipal Solid Waste Management in the State of Madhya Pradesh, India. International Journal Of Environmental Sciences Volume 3, No 1, 2012.

[14] Anyaegbunam F.N.C., (2013), Plasma gasification in waste management and sustainable renewable energy in Nigeria. International Journal of Environmental Science and Technology, July 2013.

[15] Dighe, Shyam V. (2008), Westinghouse Plasma Corporation, Madison, Pennsylvania, USA, Plasma Gassification : a proven technology, Proceedings of NAWTEC16, 16th Annual North American Waste-to-Energy Conference, May 19-21, 2008, Philadelphia, Pennsylvania, USA.

[16] Youngchul Byun, Moohyun Cho, Soon-Mo Hwang and Jaewoo Chung, (2012) Thermal Plasma Gasification of Municipal Solid Waste (MSW).

[17] Waste Gasification by Thermal Plasma: A Review Frederic Fabry, Christophe Rehmet, Vandad-Julien Rohani, Laurent Fulcheri.

[18] Vaidyanathan, J. Mulholland, J. Ryu, M.S. Smith, J. Louis, J. Circeo, Characterizationof fuel gas products from the treatment of solid waste streams with a plasma arc torch, J. Environ. Manage. 82 (2007) 77e82.

[19] J.S. Chang, B.W. Gu, P.C. Looy, F.Y. Chu, C.J. Simpson, Thermal plasma pyrolysis of used old tires for production of syngas, J. Environ. Sci. Health A31 (1996)1781e1799.

[20] L. Tang, H. Huang, C.Z. Wu, Pyrolysis of polypropylene in a nitrogen plasma reactor, Ind. Eng. Chem. Res. 42 (2003) 1145e1150.

[21] H. Huang, L. Tang, C.Z. Wu, Characterization of gaseous and solid product from thermal plasma pyrolysis of waste rubber, Environ. Sci. Technol. 37 (2003)4463e4467.

[22] W.-K. Tu, J.-L. Shie, C.-Y. Chang, C.-F. Chang, C.-F. Lin, S.-Y. Yang, J.T. Kuo, D.-G. Shaw, Y.-D. You, D.-J. Lee, Products and bioenergy from the pyrolysis of rice straw via radio frequency plasma and its kinetics, Bioresour. Technol. 100(2009) 2052e2061.

[23] W.-K. Tu, J.-L. Shie, C.-Y. Chang, Pyrolysis of rice straw using radio-frequency plasma, Energy Fuel 22 (2008) 24e30.

[24] J. Amouroux, J. Talbot, Conditions for the pyrolysis of methane in an inductive plasma of argon, Ann. Chim. (Paris) 3 (1968) 219e233.

[25] Rodat S., Abanades S., Coulié J., Flamant G., "Kinetic modelling of methane decomposition in a tubular solar reactor", Chemical Engineering Journal, 2009a,

[26] Experimental Evaluation of Indirect Heating Tubular Reactors for Solar Methane PyrolysisSylvain Rodat_ St´ephane Abanadesy Gilles Flamantz vol.8 2010.

[27] **Circeo L. J, (2012),** Plasma Arc Gasification of Municipal Solid Waste. Georgia Tech Research Institute, Environmental Science and Technology Program, Electro-Optical Systems laboratory.

[28] **Pradhan Upendra Mani, (2008),** Sustainable Solid Waste Management in a Mountain Ecosystem: Darjeeling, WestBengal, India, A Thesis Submitted to the Faculty of Graduate Studies In Partial Fulfillment of the Requirements For the Degree of Master of Natural Resources Management, Faculty of Environment Earth and Resources Natural Resources Institute University of Manitoba, November, 2008.