M.Tech Thesis

on

"Plasma Technology for Covid-19 Biomedical Waste Management"

Submitted by

Sandeep Kumar

(2K19/ENE/01)

Under the Supervision of

Prof. S.K. Singh

(Head of Environmental Engineering Department, DTU)

&

Co-guidance of

Dr. Mukesh Kumar

(Assistant Prof. Physics Department, SSN, Delhi University)

Environmental Engineering Department

Delhi Technological University

(Formerly Delhi College of Engineering)

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<u>Declaration</u>

I hereby declare that the thesis entitled **"Plasma Technology and Strategies for Covid-19 Bio-Medical Waste Management"** submitted by me for the award of Degree of Masters of Technology in Environmental Engineering of Delhi Technological University is the output of my unique and autonomous exploration work did under the guidance of Prof. S.K. Singh, Head of Environmental Engineering Department, DTU and co-guidance of Dr. Mukesh Kumar, Assistant Prof. Physics Department, SSN, Delhi University and no degree, recognition, association, university/institutions bursaries have been filed for the honour of any.

Place: Delhi

Date: 01.07.2021

(Sandeep Kumar)
2K19/ENE/01
M. Tech, Environmental Engineering

Certificate of Originality

This thesis entitled **"Plasma Technology and Strategies for Covid-19 Bio-Medical Waste Management"** submitted by **Mr. Sandeep Kumar**, for the award of Degree of Masters of Technology in Environmental Engineering of Delhi Technological University is a record of bonafide research work done by him and no degree, recognition, association, university/institutions bursaries have been filed for the honour of any.

Place: Delhi

Date: 01-07-2021

(Dr. Mukesh Kumar)
Assistant Professor, Physics Department
Swami Shraddhanand College, Delhi University

(Prof. S.K. Singh)
Head of Department of Envionmental Engineerng
Delhi Technological University

Delhi Technological University
(Formerly Delhi College of Engineering)
Shahbad Daulatpur, Bawana Road Delhi -110042

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Abstract

The urbanization period has exponentially increased the population and development and generated enormous amounts of garbage. The technological advancement has improved the medical facility of the country and with improvement in medical facilities the related waste generation has also increased. The Bio-medical waste is always a matter of concern for researchers and scientists due to its risk to the health of community. The risk increases when a new micro-organism highly contagious is nature and fatal is identified. The huge amounts of Covid-19 waste from the treatment of Covid-19 patient and PPE kits waste has become a major environmental and social concern that needs to be addressed. The Covid can support for quite a while on different surfaces which is a significant reason for its transmission. Customary strategies like combustion, land filling incineration, gasification have been the expectedly favored strategy for squander the board yet the Covid-19 waste can't be managed by conventional advancements as the pace of waste age is somewhat high and is infectious. This study will examine the socio-economic aspects of plasma technology, a more sustainable waste management system with by-product and slag production of synthetic gas. Suggestions have been made to work on the soundness of society, procedures for waste management, process performance, environmental evaluation and gasification processes for plasma,- a substitute waste to energy technique has been additionally talked about. This study also sheds light on unfavorable environmental consequences of the traditional, ones now employed techniques of Covid-19 waste management methods in India and analysis shows that Covid-19 waste can be managed using plasma gasification to prevent spread of corona virus; reduce the energy consumption; contribute to revenue generation. A small in-house Covid-19 waste treatment plant has also been suggested to reduce the risk of transmission and movement of corona virus as well as mitigating the risks associated with the hazardous portion.

Keywords: Bio-medical Waste, Covid-19 Waste, Plasma Technology, Waste Management, Waste to Energy

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Chapter-1

Introduction

1. Introduction

1.1. Solid Waste

Efficient sustainable and long-term disposal of urban solid waste is one of the most serious challenges that municipalities face. Waste challenges in cities include the growing difficulty of acquiring new dumping locations, pollution generated by processing and disposal of waste, disposal caused resource depletion and the huge cost involved in waste processing. Uncontrolled unloading of squanders on edges of town and urban communities has made spilling over landfills, which are not just truly challenging to recover due to heedless way of unloading, yet in addition have genuine ecological ramifications as far as water contamination, land degradation and air pollution adding to a dangerous Global warming . Environmental degradation is taking place and organizations that are responsible for environmental management are facing many problems and challenges. With the mechanical headway and innovation of new items and administrations, the amount and nature of the waste have changed throughout the long term. Squander qualities rely upon pay, culture and topography and furthermore on a general public's economy and, circumstances like catastrophes that influence that economy. The administration of various waste requires diverse sort of systems to deal with as the distinctive harmful mixtures that may be available in one may not be available in the other [Alam,2013, CPCB,2004, M.Kumar,2013]. The large amount of waste produced due to increase in utilities as well as population and goes to the dump or buried under the earth. 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 [Cleary, 2009, M.Kumar,2017,2018]. Recycling is one of the natural processes which our Mother Nature do, it recycles all types of waste materials that are composed of non easily breakable complex materials and to convert into new things. The natural substance of the MSW shifts between 35–60% in various parts of the country[3i Network, 2009]. The low quality of isolation has come about into low quality of final result with low market interest and the manure and waste to energy offices are dealing with issues because of this. The different conventional techniques like combustion, biodegradation has need for reusing, to use the loss in normal and eco-friendly way. Open dumping has been viewed as the least demanding and most acknowledged act of solid waste removal. On a normal, 5–6% of the wastes are disposed off by utilizing different treating the soil strategies Anotherpossibility is to burn waste, and energy can be delivered by utilizing it as a fuel however incinerators are profoundly disagreeable with neighborhood networks due to the air pollution they can create.

Table.1.1. MSW Disposal methods in various countries

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

Energy is one of the foods for technical or economic development of human beings. Rapid increase in population has resulted in huge demands for energy to for material production. Such thrust for energy and to recover more energy requires technological exploitation of energy resources (Ramos & Rouboa, 2020; Young, 2010). The materials byproducts are related to waste, an inevitable by-product of industrial production. The exponentially growing population has increased the waste production to many fold. Although waste is shown to be a unnecessary subjective part of modern creation, the quantitative scope of waste can vary according to the degree of (in) efficiency with which these processes are operated within certain limits. Over the years, new technological innovations and modern facilities has changed the amount and nature of waste. The characteristics of squander rely upon pay, culture and topography yet it additionally relies upon a general public's economy and circumstances like debacles that influence that economy (Ionescu et al., 2013; Kumar, Khare, & Alappat, 2002; Kumar, 2014; Kumar, Kumar,

& Singh, 2020; Kumar & Samadder, 2017; Leena, Sunderesan, & Renu, 2014; Rawat, Kaalva, Rathore, Gokak, & Bhargava, 2016; Vats & Singh, 2014; Vats & Singh, 2014).

1.2. Bio Medical Waste

General waste ranges from 75% to 90% which includes health-care waste and these wastes aren't harmful in any way. These wastes originate from the kitchen, administrative, Housekeeping facilities generated at healthcare centers. It also covers packaging waste and waste generated during the upkeep of healthcare facilities. About 10% - 25% of extravagance is dangerous. These types of wastes may cause a threat to variation of atmosphere and disease. The remaining i.e. 5% of waste is chemical or radioactive waste which is also hazardous. These are types of waste from sealed sources, like diagnostic tools, that can cause wounds along with destruction of the tissue, which require amputation of the body parts, etc. Health centers producing medical wastes are expanding continuously every year in their amount and category. These different categories of waste possess contamination to Human beings and the environment. The waste-producing are of major and minor sources which are stated below:

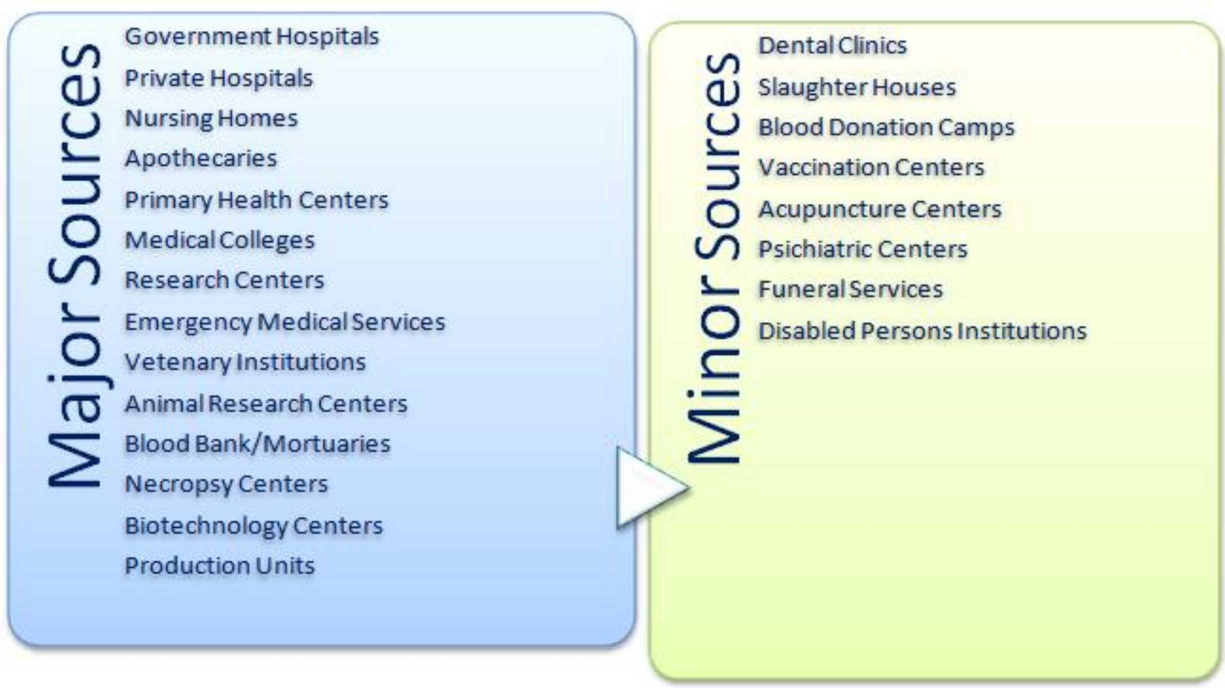

Fig.1.1 Sources of Bio-Medical Waste

Waste challenges in metropolitan centers include the growing challenge of acquiring expensive land for disposal, producing emissions from waste treatment and disposal, etc (Sharma & Shah, 2005; Vats & Singh, 2014). The disposal of waste has caused resource depletion and the huge cost involved in waste processing and transportation. Established processes for the collection, transport and treatment of solid waste are mired in confusion in India. Uncontrolled waste disposal has created overflowing landfills on the outskirts of neighborhoods, which are not only very difficult to retrieve due to haphazard dumping practices, but can have significant environmental effects in terms of water contamination, land degradation and air pollution that lead to global warming. Environmental degradation is taking place and organizations that are responsible for environmental management are facing many problems and challenges. Uncontrolled waste disposal and unsustainable waste management not solely harm the atmosphere, but conjointly have an effect on human health (Central Pollution Control Board (CPCB), 2004; Jha, Singh, Singh, & Gupta, 2011; Kumar & Samadder, 2017). The new scheme relies on the storage and transport of mainly mixed, unsegregated waste. The 5R solution - Recycling, Reduce, Reuse, Refuse, Recover, Residual Management with sustainable disposal of residual waste in science-based landfills is grossly ignored (Abhishek & Mukherjee, 2019; Alam & Ahmade, 2013; Anubhav, Abhishek, & Durgesh, 2012; Cleary, 2009; Kumar et al., 2017; Nandan, Yadav, Baksi, & Bose, 2017; Otitoju & Seng, 2014; Srinivas, 2007; Sudha, 2008; UN, 2000; World Energy Council Report, 2013; Young, 2010). This work explores the solid waste production status and its environmental and financial impact on Indian cities. This study also analyses the growing number of municipal solid waste (Kumar et al., 2016; Sudha, 2008; World Energy Council Report, 2013) the changing nature of municipal solid waste, from biodegradable waste, dry waste to the increasing volume of plastic in the waste (Cleary, 2009; Devi & Satyanarayana, 2001; Hargreaves, Adl, & Warman, 2008; Indo-UK Seminar Report, 2015 ; Jha et al., 2011; Kumar & Samadder, 2017). This work also presents the sources of waste-to- energy / energy-from-waste conversion technology for the solid waste sector. Laws for sustainable solid waste disposal have already been set in motion, but a big obstacle is the need to plan and maintain the scheme and ensure implementation of the rules (Sharma & Shah, 2005; Vats & Singh, 2014). In addition to providing some mitigation options to respond to the growing problem, current governments recommend publicly-engaged frameworks to ensure that the framework is financially sustainable. There are many cleaner technologies for dealing with waste but lack of knowledge and public awareness makes waste management a menace. Public participation is required to deal with the generated waste at source itself.

Fig.1.2. Bio-Medical waste

1.3. Covid-19 Waste

This century is acknowledged for its exponentially growing human population and industrial development, as well as the Covid-19 pandemic. Nature's pandemic counter-forces have been harmed as a result of our rapid industrial waste growth. As a result, almost every country in the world is under lockdown or a series of lockdowns as a result of Covid-19(WHO,2020). The various steps have been taken to prevent/fight this lethal pandemic, with measures like sampling, testing, patient isolation, personal protective equipment (PPE), social distancing, and life-supporting treatments. It also includes personal measures such as practicing social distancing, wearing mask & gloves, frequent hand washing, etc. Prior, individual defensive gear (PPE), surgical (and defensive) facemasks, covers/outfits, and nitrile gloves are basically used to shield people from openness to microbes and impurities (Wan et.al. 2020) yet COVID-19 has utilized homegrown disengagement and individual protections vital, bringing about a quick development of possibly irresistible waste streams (hereinafter, COVID-19-waste)(Singh et,al. 2020). Waste produced in investigation, treatment, or immunization of infected patients or in research activities or during the handling and management of waste in the process is termed as 'Covid-19 Waste' (BMW, rules, 1998. Das et.al 2020). Approximately, 3-5 kg of waste is generated in the treatment of one patient [CPCB, 2020]. The Covid-19 waste is highly infectious and worsening the situation. Various studies shows that this virus may last a long period from 2 hours to 3 days on different surfaces which can be considered as important reason for its transmission. The new mutated version of the virus has a fast transmission and has the potential to contaminate the environment progressively. So the waste management is critical to control the spread of the virus (Chartlier et.al 2014. Datta, et.al. 2018). More waste will lead to more transmission and spread of the virus.

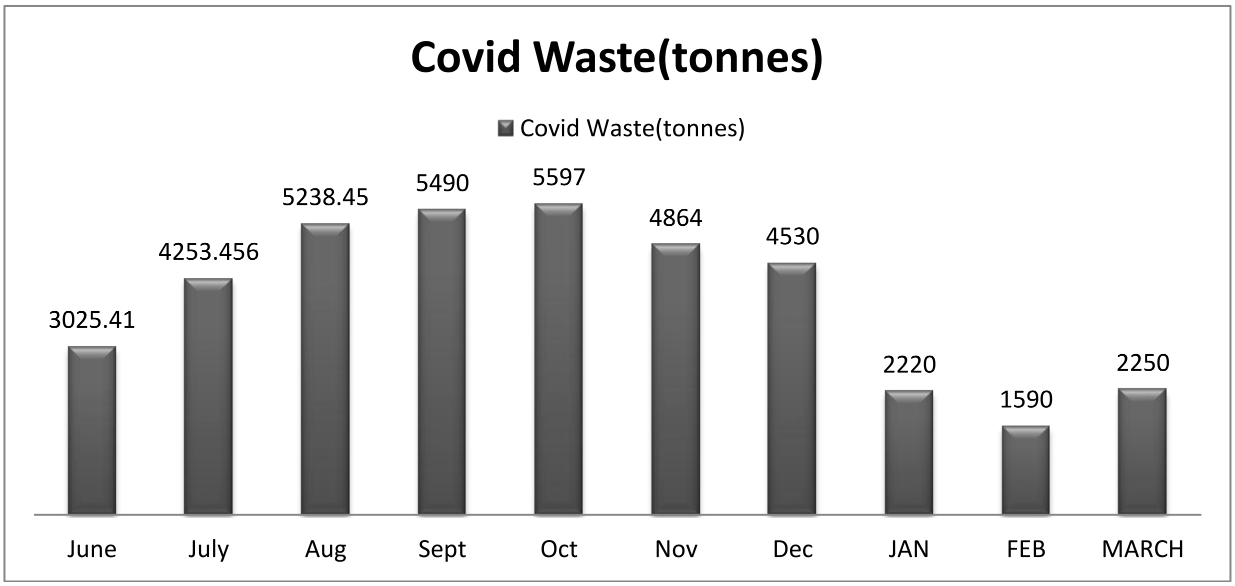

Fig.1.3. Covid-19 Waste statistics in India

The Government agencies like WHO, CPCB, Ministry of health have given guidelines from time to time to deal with Covid-19 waste in hospitals and also for isolations (Ilyas,et.al. 2020. Mathur et,al. 2011). As per CPCB guidelines, the Covid-19 Waste should be disposed of along with biomedical waste as per BMWM rules, 2016 through authorized Common CBWTFs (Common Biomedical Waste Treatment Facilities) or captive treatment facilities such as deep burial pits (where CBWTF is not available). According to the WHO, communicable waste generated from treatment of patients, particularly those with confirmed COVID-19 virus (e.g. sharps, bandages, pathological waste), should be carefully contained in clearly designated lined containers and sharp boxes. The clinical waste overseer should wear proper PPE (long-sleeved outfit, rock solid gloves, boots, cover, and goggles or a face safeguard) and perform hand cleanliness subsequent to eliminating it (MoHFW, 2020, WHO, 2020. Pasupati et.al. 2011).


Fig.1.4. Heaps of Covid-19 waste

A modern waste processing technology called plasma arc recycling (sometimes referred to as "plasma recycling," "plasma gasification," "gas plasma waste treatment," "plasma waste recycling,"etc.) means to change this. The waste is heated at very high temperatures to deliver gas that can be burnt for energy and rough strong waste that can be utilized for various purposes. It is an environmental friendly technology for waste treatment [Ana, 2020]. This project studies the behavior of Covid-19 spread in view generated Covid-19 waste. This work also assesses the Covid-19 risk probability during waste transportation and management. This also studies and analyzes the various technologies used for waste management. It is found that modern plasma-based technology is a safe and viable option for such risky waste. This will remove the waste-induced Covid-19 risk and offer efficient waste management. An in-house micro-plasma Covid-19 waste treatment waste plant model is suggested for efficient management.

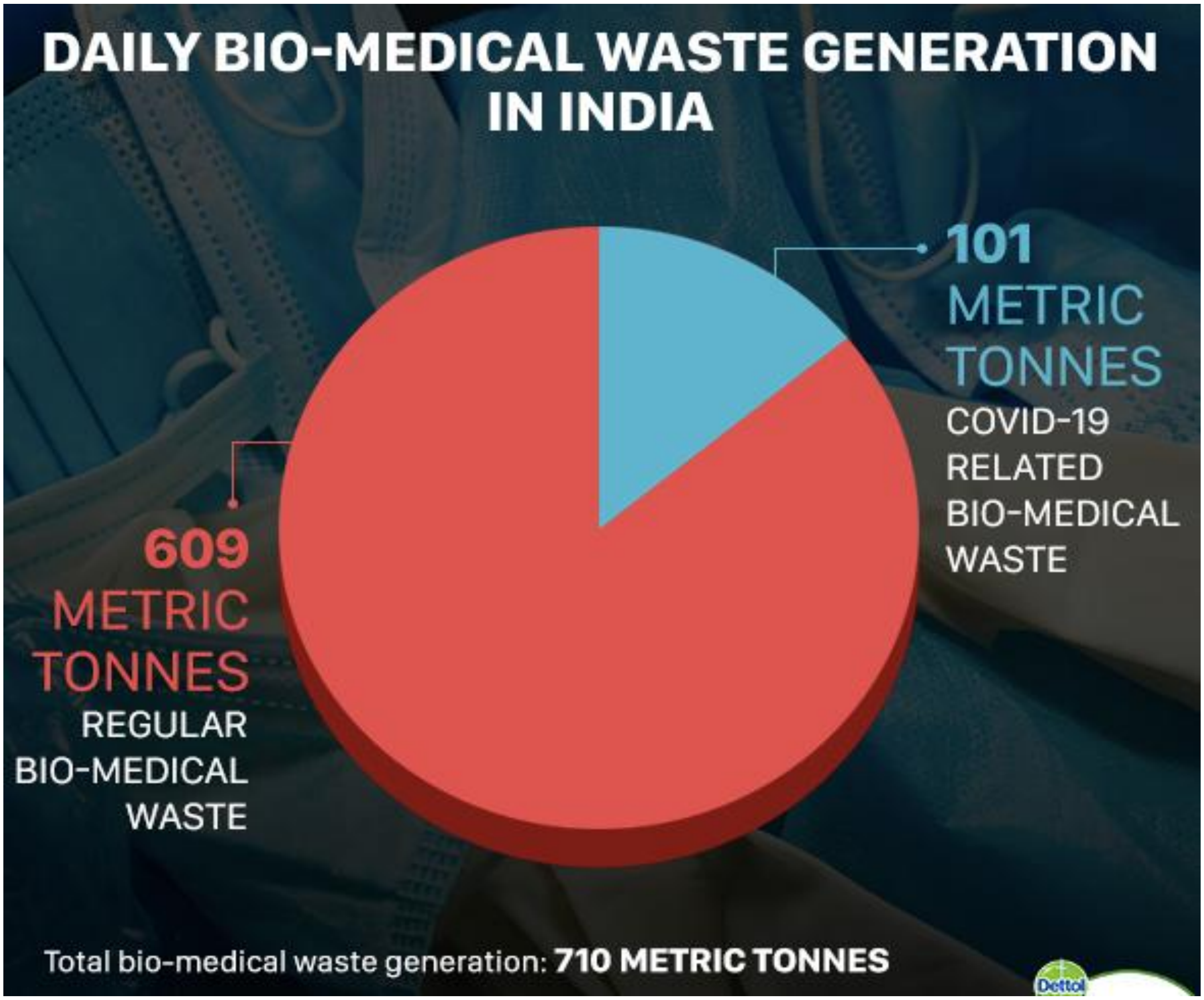

Fig.1.5. BMW and Covid-19 waste generated in India (Central Pollution Control Board (CPCB))

1.4. Statement of the problem

The waste produced in sampling, testing, and diagnosis of Covid-19 patient is highly contagious and can be transmitted through materials/ surfaces. Some waste from medical facility is also highly infectious which needs immediate treatment. The waste generated is large in quantity so existing treatment processes are not sufficient in dealing such wastes so there is a need to find, understand and evaluate some advanced techniques for the treatment of contagious and hazardous waste.

1.5. Scope of the study

This study is aimed at determining biomedical waste management practices and its impacts with special reference to Covid-19 Waste management. The present study helps to understand the various treatment given to the bio-medical waste in India with special emphasis on Plasma technology. The findings of the study are helpful in formulating a suitable and less harmful strategy for proper disposal of Covid-19 waste and other infectious waste without compromising with the safety of public health. The findings can be useful for the planners and implementers for taking adequate steps to provide advice and support for establishing modern technologies for infectious and hazardous waste which can be harmful if not handled properly.

1.6. Research aim & objectives

Aim

The research is aimed at finding a new approach to deal with the treatment of highly infectious diseases such as corona, bio- medical wastes and other hazardous wastes.

Objectives

1) To study the current BMW management practices and disposal methods.
2) Assessment of Technologies for BMW management and their limitations.
3) To establish the relation between Covid-19 waste and Covid-19 cases.
4) To guage the various limitations in successful Covid-19 waste management.
5) Role of Plasma technology in dealing Covid-19 waste.
6) Designing Micro-Plasma model for treatment of Covid-19 waste at the source.

1.7. Limitations

This study has been conducted on the basis of secondary data from CPCB, journals, papers et. Due to Covid-19 pandemic, visit to hospitals and medical facilities have been avoided. The plasma gasification plant has a huge set up, requires skilled people for its operation and risk of Covid-19 spread restricted the study of practical application of the plasma gasification.

Chapter-2

Literature Review

2. Literature Review

This chapter reviews the literature available which is relevant and useful for identification and focusing attention on the problem and interpretation of the data.

The review of the literature is organized into 4 groups:

i. Literature review related to Solid waste management
ii. Literature review related to Bio-medical waste management
iii. Literature review related to Covid-19 waste management
iv. Literature review related to Plasma technology

2.1. Literature review related to Solid waste management in India.

A research was done on rates for municipal trash generation at sub-tropical high altitude, physical and chemical characterization of solid waste. In the North-East states of India, the research concentrated on hilly terrain. The pace of MSW generation was discovered to be dependent on the residents' lifestyle trends rather than population. The effectiveness of garbage collection has been shown to be only 70%, and baseline data has revealed that population and MSW creation rates are unrelated. It was also discovered that the biodegradable proportion in the collected MSW was greater than 50%, indicating a high organic content appropriate for the production of compost for agricultural application. The debris was either hauled to landfill locations, deposited on hill slopes, or even burned openly at landfill sites. The average ash level was determined to be 43.48 percent, which could be attributed to the research area's regular open burning and dumping practises (sunil.et.al.2016).

A study was conducted on Characterization of municipal solid waste at landfill, India. It was found that From 2001 to 2008, the city's trash creation had a significant impact, which can be attributed to the city's general economic expansion. From 51.5 percent in 2001 to 69.3 percent in 2008, organic matter had increased. The number of city scavengers who collect recyclable things has increased, leaving only organic debris and non-recyclable materials as waste. The quantity of cafés and inns has developed, prompting the expansion of natural matter. Due to the high biodegradable part, solid waste must be collected and removed from collection points on a regular basis. Between 2001 and 2008, the amount of recyclable material increased by 9.57 percent, owing to changes in lifestyle, economic status, material consumption patterns, educational institutes, the IT sector, and the throw-away culture, among other factors. The MSW from the Pune city landfill site was characterised and found to possess a high percentage of organic matter (69.3%), organic content in MSW of 32.83 percent, and average moisture content of 48.08 percent, indicating that biological treatment is viable. This expansion has given rise to the practise of scavenging, which employs hundreds of unskilled labourers, particularly in the city and landfill areas. Because the organic content was low and the moisture level was high, incinerating MSW for energy generation was not possible. 2011 (Sandip.et.al.)

In India, a research was carried out on the challenges and opportunities related with trash management. In India, population increase is a primary factor to rising MSW. The nearby economy affects squander structure since higher-pay bunches burn-through more packaged items that bring more plastics, paper, glass, metals and minerals in the waste stream. The typical MSW mix generated in India is roughly 41 weight percent organic, 40 weight percent inert, and 19 weight percent possibly recyclable elements. Waste collection, storage, and transportation are critical components of any SWM system, but they can be difficult in cities. Dumping of blended biodegradable and idle waste is incessant, as is open consuming. Neighborhood governments spend generally Rs. 500–1000 for every ton on SWM, with 70% of that going to collection and 20% to transportation. In India, it is estimated that more than 90% of trash is disposed of in an unacceptable manner. Under anaerobic conditions, methane is delivered from open dumps as biodegradable trash breaks down. Methane is a vital supporter of an Earth-wide temperature boost and causes blazes and blasts. There is a shortage of gifted waste administration subject matter experts and there is a lack of preparing in SWM. In India's present SWM frameworks, there is additionally an absence of responsibility. City governments in India are responsible for taking care of MSW, yet their financial plans are deficient to pay the expenses of developing legitimate trash assortment, stockpiling, treatment, and removal frameworks. In India, accomplishing effective SWM is hampered by an absence of key MSW plans, squander assortment/isolation, and an administration monetary administrative system. Low inspiration and an absence of ecological information have smothered advancement and the reception of imaginative innovation that could further develop trash the board in India. In India, public perspectives around wastes are likewise a critical hindrance to creating SWM (kumar.s,2017).

2.2. Literature review related to Bio-medical waste management

A study was done utilising pre-designed questionnaire on the knowledge, attitudes and behaviours of health professionals with relation to the BMWM Rules of 2016 (Principles) and 2018 (Adjustments), 2016 Solid Waste Rules, and Health Risks. Only 68 percent were aware that the most important stage in waste management is garbage separation. The different color-coded segregation bins were known to 82% of HCWs functioning under this system. However, there was a lack of understanding of the health hazards of poor separation and waste disposal as just 49 percent properly responded to concerns concerning waste hazard. Lab waste dealing with was discovered to be the most un-comprehended space of the more up to date rules (Annapurna.et.al.2019).

In rural India, a cost comparison of biomedical waste management across different bed strengths was undertaken. Compliance with the rules of bio-medical waste management (Management & Handling), 2011 at three different hospitals, was investigated in a descriptive cross-sectional study. Cost data for a one-year period was analysed in a retrospective research. Compliance in accredited hospitals was shown to be higher than in non-accredited hospitals. This could be due to personnel training and careful adherence to standard operating procedures. BMW management costs were broken down into capital and intermittent expenses. Since a large portion of the medical clinic rethink last removal, Capital expenses are altogether less contrasted with repeating costs (D'Souza et al.2017).

2.3. Literature review related to Covid-19 waste management

The Escalating Biomedical Waste Management to Control the Environmental Transmission of the COVID-19 Pandemic: A Perspective from 2 South Asian Countries was the subject of a study. Waste management agencies around the world are battling Covid-19-related bio-medical waste. Environmental and local area According to a study carried out in India and Bangladesh, transmission of the COVID-19 pandemic from BMW in health facilities and homes is not properly managed. The risk of infections spreading among garbage workers and the general public has increased as the amount of untreated BMW has increased. Long-term, safety suits and personal protection equipment will harm the environment by causing micro-plastic contamination. Because of the coronavirus's aerosol and surface stability, contaminated face masks, gloves, and PPE from hospitals and confined households may pose a greater risk of environmental risks and transmission. A credible BMW management system was found to be lacking in 82 percent of primary, 60 percent of secondary, and 54 percent of tertiary health centres. There have also been suggestions for changes to regulations and rules. Other methods, such as industrial furnaces and kilns, have been suggested as alternatives to incineration. (shammi. et.al, 2021)

Compromising status of India's bio-medical waste incineration facilities during pandemic breakout of COVID-19: Associated environmental-health consequences and mitigating methods was conducted by thind.et.al in 2021. In India, it was discovered that the presence of Covid-19 patients in health institutions enhanced yellow BMW category generation and increased the combustion unit strain. On average, 3.41 kg of Covid-19 waste is generated per patient each day, with y-BMW accounting for half of that. BMW's incineration capacity has also been entirely utilised, according to the findings. NOx > CO > SOx > PM > HCl > Cd > Pb > Hg > PCBs > Ni > Cr > Be > As were the pollutant concentrations emitted in that order. Alternative waste treatment methods have been compared, including autoclave, microwave, pyrolysis, and gasification. It has been discovered that an alternative treatment procedure is required to treat significant amounts of garbage in a short period of time.

PPE and other COVID-19 patient waste can act as a vector for this disease and can survive up to 7 days on surfaces, according to a study on Disinfection technologies and methods for COVID-19 hospital and bio-medical waste management. As a result, it was proposed that waste should be disposed of immediately. For Covid-19 waste, numerous sanitization techniques have been researched. Synthetic sterilization utilizing a 1 percent NaOCl arrangement is truly outstanding in-situ systems that is extremely simple to splash and isn't just valuable for COVID-19-squander yet in addition for disinfecting greater spaces, shopping centers, clinic premises/wards, and confinement focuses. Burning is valuable to handle a bigger quantity of COVID-19 waste which is an energy-concentrated interaction however dependable cycle because of a high working temperature (800–1200 °C). The strategy like "Identify, isolate, disinfect, and safe treatment practices" has been discovered to be compelling for more secure administration of COVID-19-waste. (Ilyas.et.al, 2020)

2.4. Literature review related to Plasma technology

A study on technological elements of thermal plasma treatment of municipal solid waste was carried out. It was discovered that the vast amount of waste generated as a result of population growth is challenging to handle using traditional waste disposal methods. Combustion/incineration has the disadvantage of producing pollutants such as dioxins and furans. A plasma torch alternative is being investigated. Plasma technique eliminates waste by up to 95% while producing syn gas without emitting any harmful gases. If financial constraints can be overcome, plasma technology is the most effective waste treatment option (Ruj.et.al. 2014).

Munir.et.al. did a study on Plasma gasification of municipal solid waste for waste-to-value processing in 2019. Plasma technology was discovered to have a high potential to transform municipal solid waste for the circular economy into value. Knowledge gaps, research, and cost are the obstacles that must be addressed in order for it to be implemented. The road plan for overcoming these obstacles was also discussed. The revenue from the process's generated fuel and gases can be used to manage the operation's costs.

A study on Energy Generation from Municipal Solid Garbage by Innovative Technologies - Plasma Gasification was undertaken, in which it was discussed that there are a variety of strategies for managing municipal waste and diverting it from landfills. Plasma gasification has been found to be the most effective approach for municipal garbage management, and it may be used by any municipality. Other techniques of solid waste treatment produce harmful residue, while plasma technology allows for total disposal. To make the procedure accessible and inexpensive to everyone, it must be designed in a unique way (Rajasekhara. M.et,al, 2015).

Chapter-3

Methodology

3. Methodology

The project is a published data based research, drawing inferences from existing literature as well as data published by CPCB. The research was conducted as per the fig.__ . a comprehensive review of the literature was prepared related to the subject matter. The current waste generation and management technologies have been reviewed, compared and their limitations have been studied for Solid Waste Management, Bio-medical waste management and Covid-19 waste management. Plasma technology is also reviewed for the treatment of all type of waste especially Covid-19 Bio-Medical Waste as it is highly infectious. A small micro plasma based model is designed for the treatment of Such hazardous waste at the point of generation i.e hospitals.

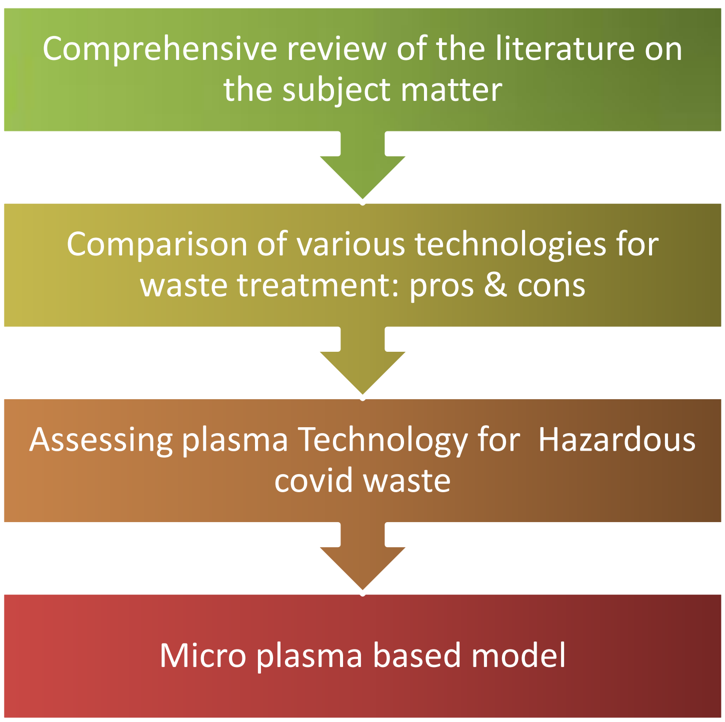

Fig.3.1. Methodology of the study

Chapter-4

Indian Scenario

4. Indian Scenario

India, the second most populated country in the world and also, one of the quickest developing economies, is encountering remarkable development in its modern area and is going through fast urbanization. The population of India is approximately 1.3 billion and experts believe that each day a single person is generating 450 grams of waste (Central Pollution Control Board (CPCB), 2000, 2004; Kumar et al., 2016). Current rate of municipal waste projection as per population growth is shown in Table 4.1.

Table: 4.1. Waste generation projection as per population growth.

Year	Population (in millions)	Total waste generation @0.4 Kg/capita/day (million MT/year)	Total waste generation @0.6 Kg/capita/day (million MT/year)
2015	1310.15	191.2819	286.9229
2020	1381.59	201.7121	302.5682
2025	1450.52	211.7759	317.6639
2030	1503.64	219.5314	329.2972
2035	1553.723	226.8436	340.2653
2040	1592.69	232.5327	348.7991
2045	1620.61	236.6091	354.9136
2050	1639.17	239.3188	358.9782

Source: Population data from worldometer web

Table: 4.2. City-wise waste composition percentage

City	Paper	Textile	Leather	Plastic	Metal	Glass	Ash	Compostable matter
Delhi	6.6	4	.6	1.5	2.5	1.2	51.5	31.78
Ahemdabad	6	1		3			50	40
Vishakapatnam	3	2		5		5	50	35
Varanasi	3	4		10			35	48
Vadodara	4			7			49	40
Surat	4	5		3		3	45	40
Pune	5			5		10	15	55
Patna	4	5	2	6	1	2	35	45
Nagpur	4.5	7	1.9	1.25	0.35	1.2	53.4	30
Madurai	5	1		3			46	45
Madras	10	5	5	3			33	44
Ludhiana	3	5		3			30	40
Lucknow	4	2		4	1		49	40
Kochi	4.9			1.1			36	58
Kanpur	5	1	5	1.5			52.5	40
Jaipur	6	2		1		2	47	42
Indore	5	2		1			49	43
Hyderabad	7	1.7		1.3			50	40
Coimbatore	5	9		1			50	35
Calcutta	10	3	1	8		3	35	40
Bombay	10	3.6	0.2	2		.2	44	40
Bhopal	10	5	2	2		1	35	45
Bangalore	8	5		6	3	6	27	45

Source: CPCB

The study predicts that MSW generation will reach 219- 330 million MT/year by 2030 and 240-358 million MT/year by 2050. Much variability of per capita waste generation is found in accordance with the size and class of the cities. As per CPCB report, in 2012, 1,27,486 tons per day of MSW is being produced from household activities and other commercial & institutional activities (Abhishek & Mukherjee, 2019; Kumar et al., 2016; World Energy Council Report, 2013).

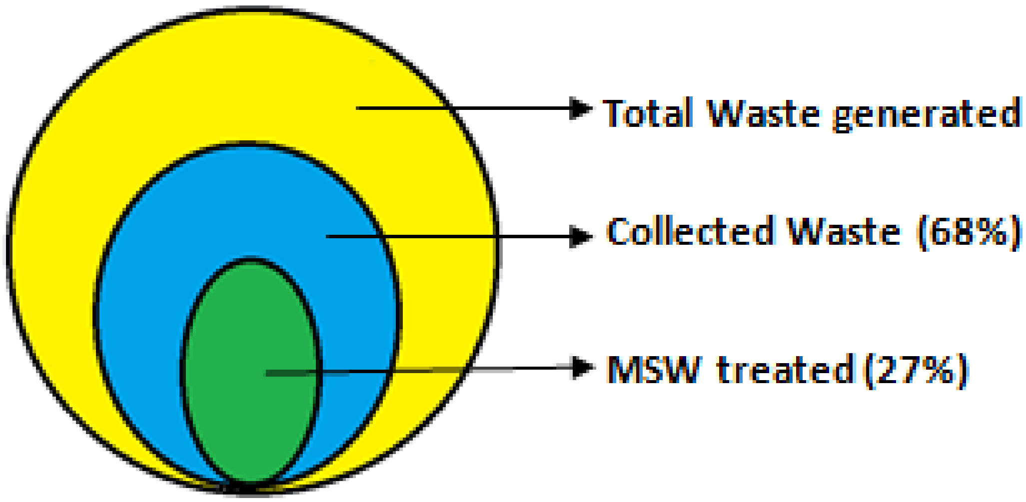

Fig.4.1. Current Municipal Waste management (CPCB)

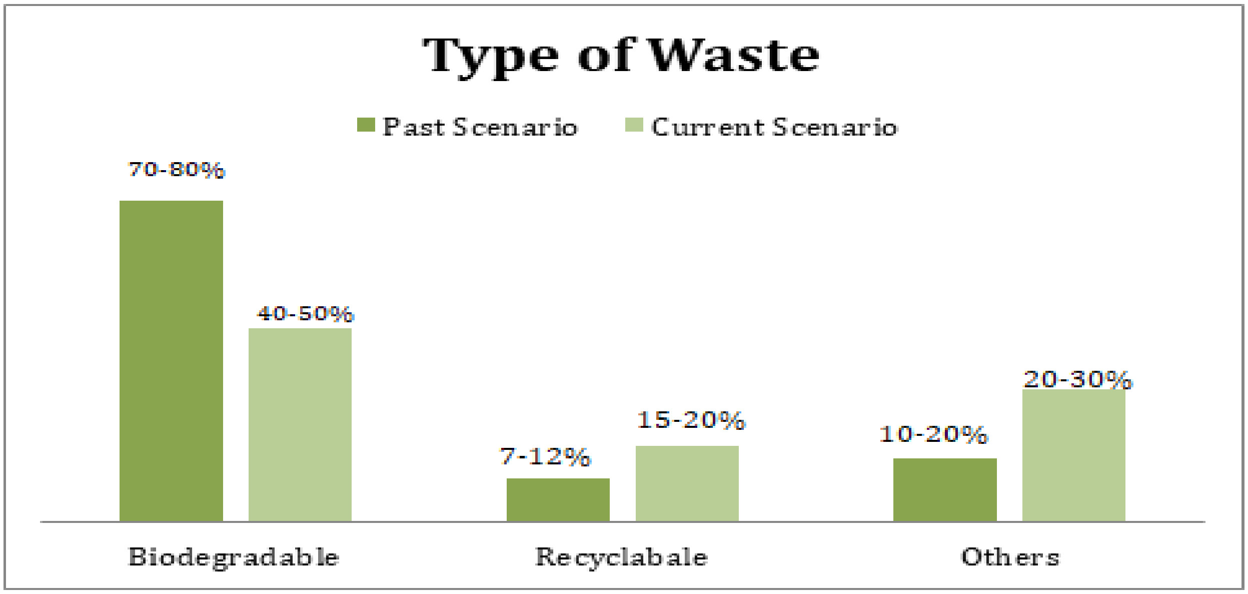

Fig.4.2. Changing Waste Scenario
Source: Abhishek and Mukherjee (2019); Nandan et al. (2017); Paulraj, Bernard, Raju, and Abdulmajid (2019).

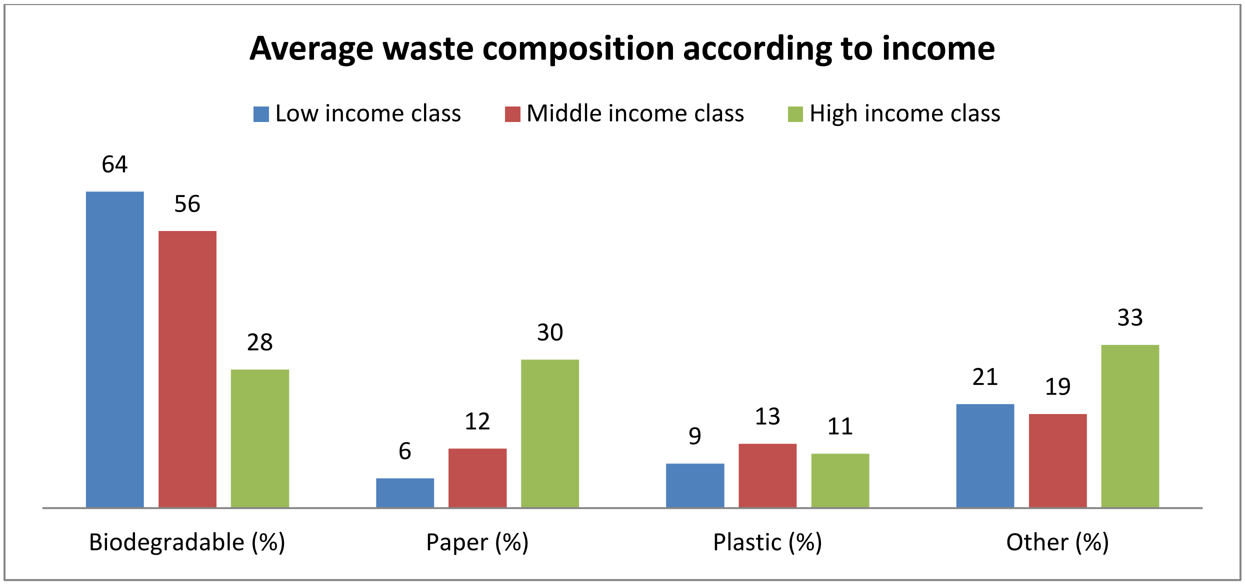

Fig.4.3. Income wise waste composition (Source: Atul Kumar,2017)

There is no distinction in the sorts of waste created in the actual portrayal information of MSW in metropolitan cities of India for the last 2 decades, although there is an increase in the quantity of waste produced. Figure 1 show that the urban MSW in India can be classified as 40-50% biodegradables, 15-20% recyclables and 31% of inert wastes with moisture content of 47% and average calorific value of 7.3 MJ/k (Jha et al., 2011; Kumar et al., 2017; Kumar et al., 2020; Leena et al., 2014).

Table 4.3. State wise Waste Segregation followed

States	Percentage source segregation
Andhra Pradesh	96.8
Andaman & Nicobar	95.83
Arunachal Pradesh	14.67
Assam	39.02
Bihar	32.78
Chandigarh	92.31
Chhattisgarh	100
Daman & diu	100
Dadar & Nagar Haveli	100

Delhi	20.07
Goa	79.72
Gujarat	83.18
Haryana	62.5
Himachal Pradesh	98.59
Jammu & Kashmir	12.67
Jharkhand	80.69
Karnataka	57.15
Kerala	100
Madhya Pradesh	98.45
Maharashtra	86.67
Manipur	64.05
Meghalaya	23.68
Mizoram	87.12
Nagaland	12.82
Odisha	69.27
Pudducherry	95.08
Punjab	85.3
Rajasthan	82
Sikkim	94.34
Tamil Nadu	84.99
Telangana	47.72
Tripura	78.39
Uttar Pradesh	69.08
Uttarakhand	57.18
West Benngal	18.99
Total	**74.82**

Source: Central Pollution Control Board (CPCB) (2000) and Central Pollution Control Board (CPCB) (2004) and Satpal (2020); Sudha (2008).

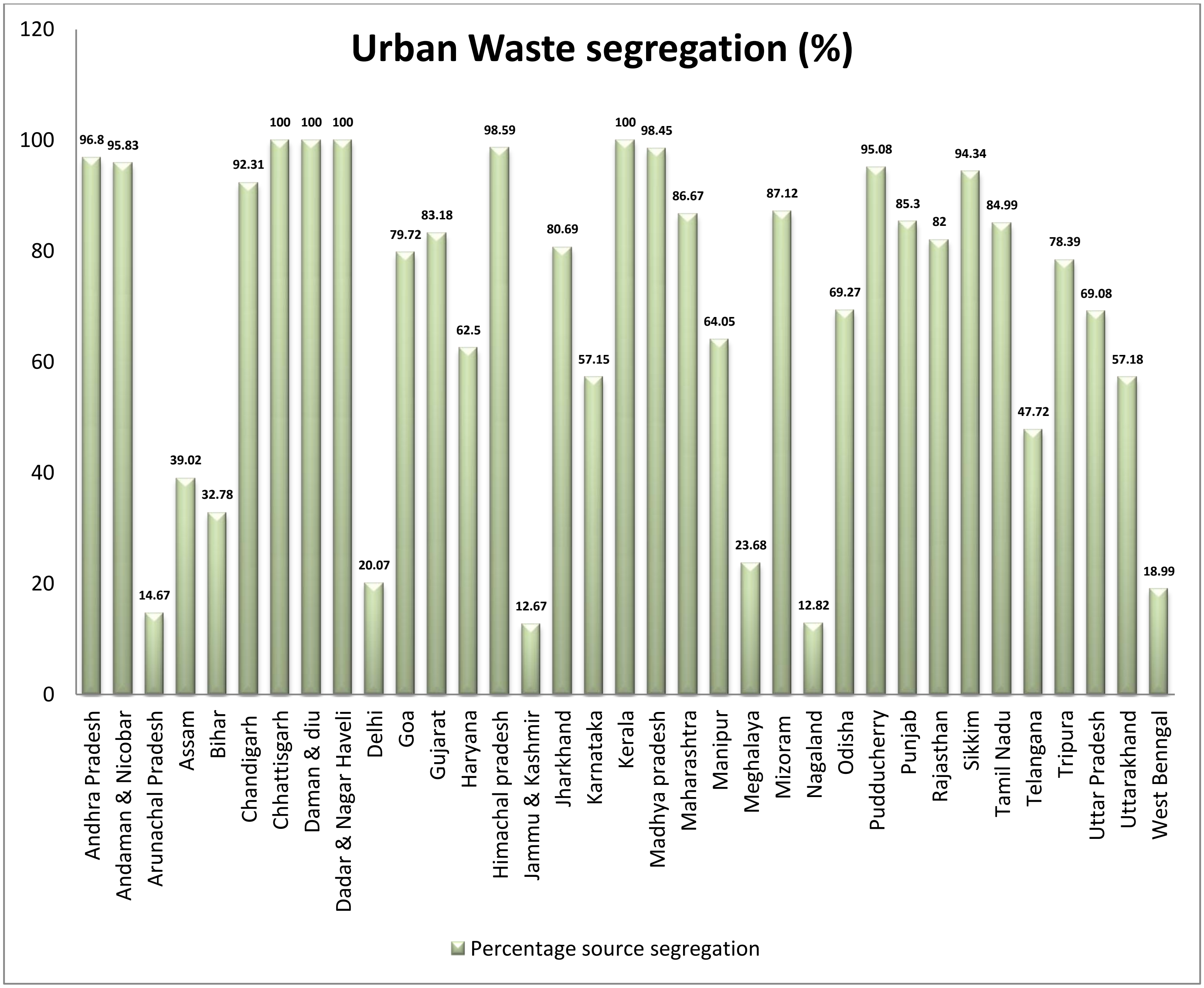

Fig.4.4. Urban Source Segregation chart
Source: Central Pollution Control Board (CPCB) (2000) and Central Pollution Control Board (CPCB) (2004) and Satpal (2020); Sudha (2008).

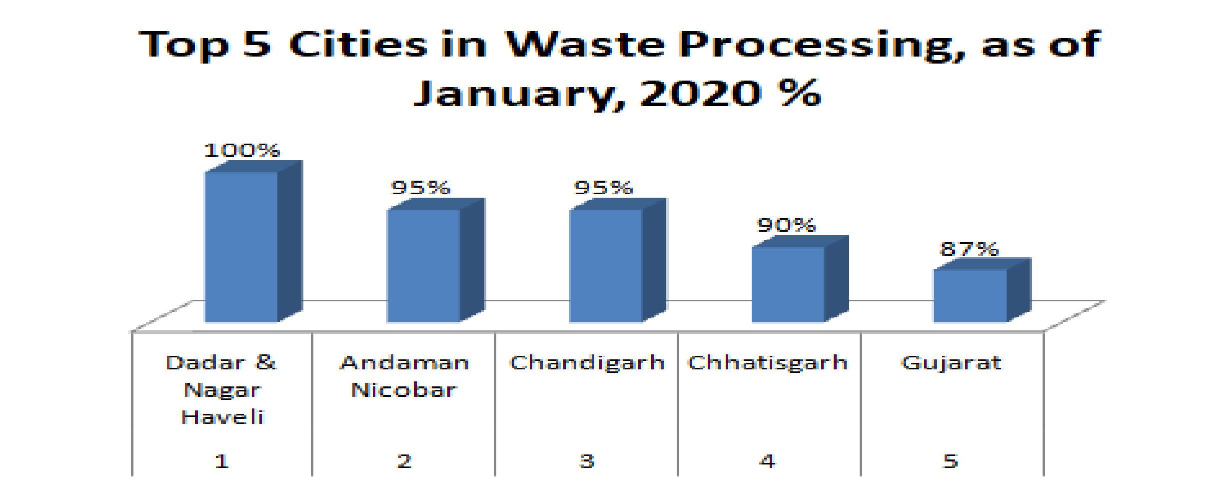

Fig.4.5. Top Cities in waste processing
Source: Central Pollution Control Board (CPCB) (2000) and Satpal (2020)

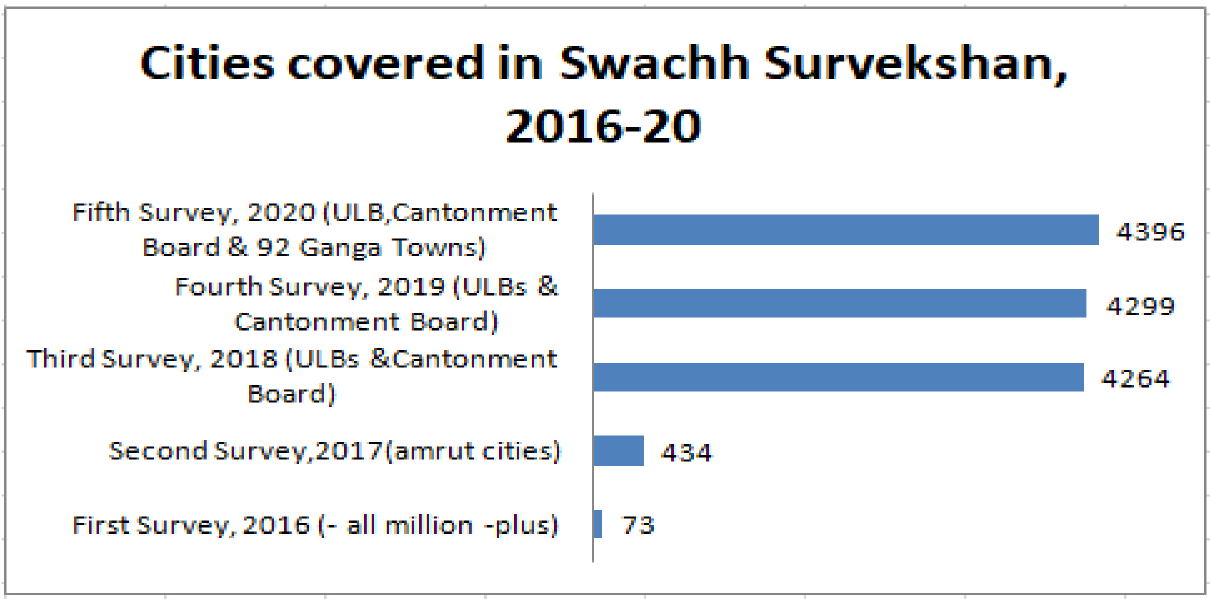

Fig.4.6. Cities coverd in swachh survekshan.
Source: Kumar (2013); Rada, Istrate, and Ragazzi (2009), Central Pollution Control Board (CPCB) (2000) and Satpal (2020).

4.1. Bio Medical Waste

As emerging countries enhance their health-care infrastructure, the volume of medical waste generated will inevitably increase. As a result, regulatory bodies and organisations around the world are paying attention to medical waste and the difficulties surrounding its processing and disposal. A study from India's National Environmental Research Institute estimated trash generation to be between 0.5 and 2.0 kilogramme per bed/day and 0.33 million tonnes per year (Patil & Shekhar, 2001). Energy and resource consumption will follow the same trend as trash production. The varied character of the waste created in the medical community is one of the problems of successful medical waste management. This makes it difficult to determine which types of trash require specific treatment, as well as how facilities can efficiently implement waste segregation.

India has both government (6 lakhs hospital beds and 23,000 primary health centers) and private (15,000 private and personal hospitals) health sector. This sector generated biomedical waste is about 50 to 60% of the total solid waste generated (Singh. A et al, 2019. Singh J. et.al. 2019). This biomedical waste is harmful and contagious need special treatment. As per the studies conducted in India, the average biomedical waste generation is in the range of 1.5 to 2 kg/bed/day. India generates around 3 million tones of medical waste consistently and the sum is relied upon to develop at 8% yearly. Except for in big cities, several individual hospitals do not have an effective system for the proper disposal of their waste in smaller hospitals or nursing homes. These health establishments have deposited waste in local municipal containers or, even worse, outside without caution or care. Illegal recycling of clinical waste by rag pickers or rubbish collectors has been promoted as a result of such careless duping. A brief summary of the provisions in Bio-medical Waste9Management & Handling) rules, 1998 is given below:

- Section 3 establishes the government's authority to take various actions for environmental protection and improvement.
- Section 5 allows for written instructions.
- Section 6 authorises the government to make rules.
- Section 8 authorises the instruction of personnel dealing with hazardous waste regarding various safety measures.
- Section 10 grants permission to access and investigate the premises.
- Section 15 empowers the government to impose penalties on defaulters. This can result in a sentence of up to 5 years in prison or a fine of up to Rs. 1 lakh, or both. If the default continues, a penalty of rupee 5,000 per day for up to one year will be imposed, followed by imprisonment for up to seven years.
- In the event that government departments violate the law, Section 17 provides for penalties.

4.2. Covid-19 waste and Covid-19 cases relation

The Covid-19 BMW have increased risk, contagious waste nature, which is a major concern. The survey found a large variation in month wise Covid-19 waste generation. In June, India produced 3,025.41 tonnes, a rise to 4,253.46 tonnes, in July and in August at 5,238.45 tonnes. Around 183 tonnes of biomedical waste were produced daily by India in September, associated with COVID-19. In June [CPCB, 2020], the number was 101 tonnes per day. In addition to normal bio-clinical waste production of about 609MT per day, COVID-19 waste is produced. (as of June, 2020).

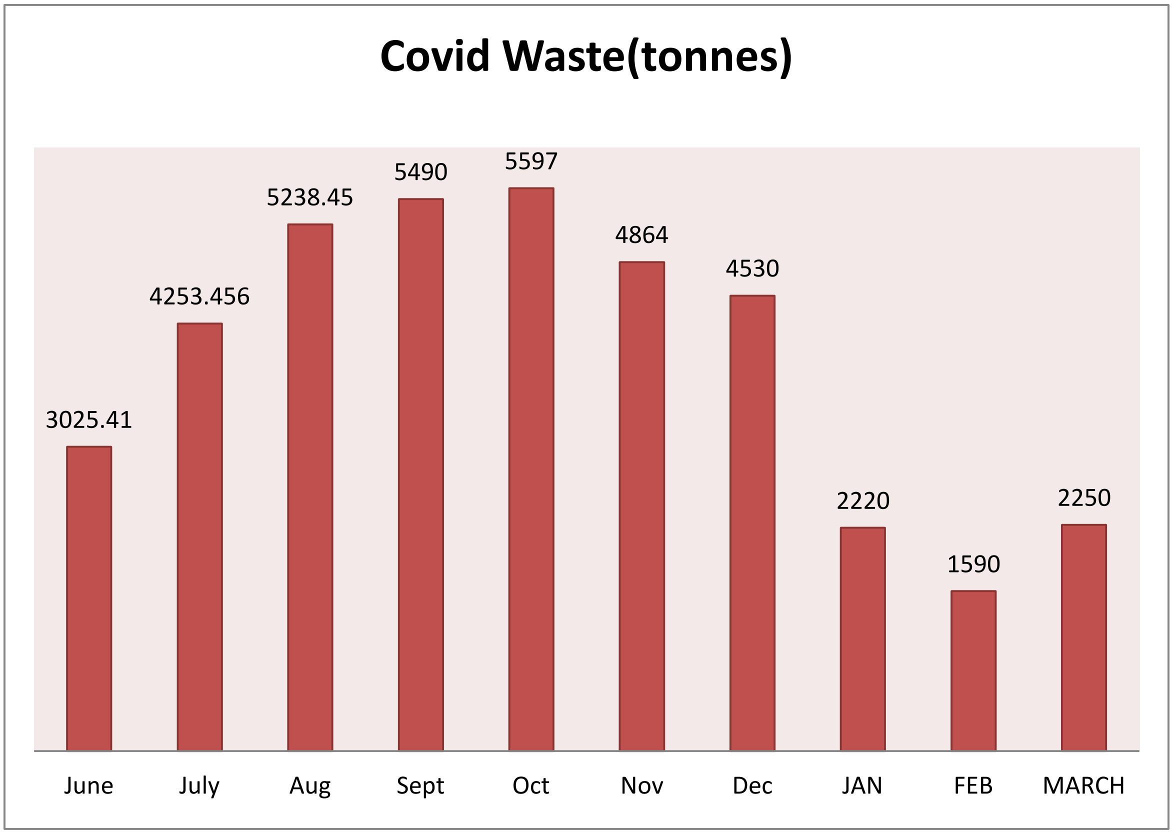

Fig.4.7. Covid-19 Waste generated June,2020 to March, 2021
Source: Central Pollution Control Board(CPCB)

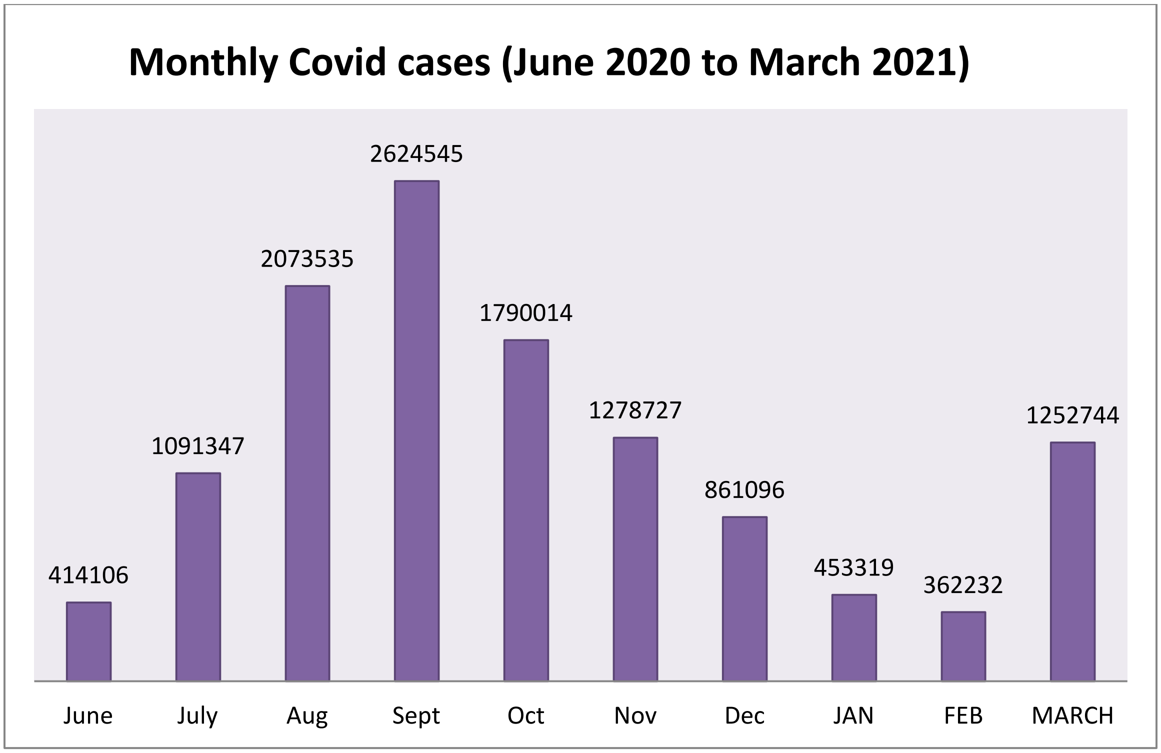

Fig.4.8. Covid-19 Cases June,2020 to March, 2021
Source: Central Pollution Control Board (CPCB)

On comparing data of Covid-19 waste and no of Covid-19 waste generation, it has been found that there is a close relation between Covid-19 waste generation and Covid-19 cases. They found almost similar trends between them as shown in fig 4.9. The Covid-19 cases are have increased with increase in Covid-19 waste and vice versa.

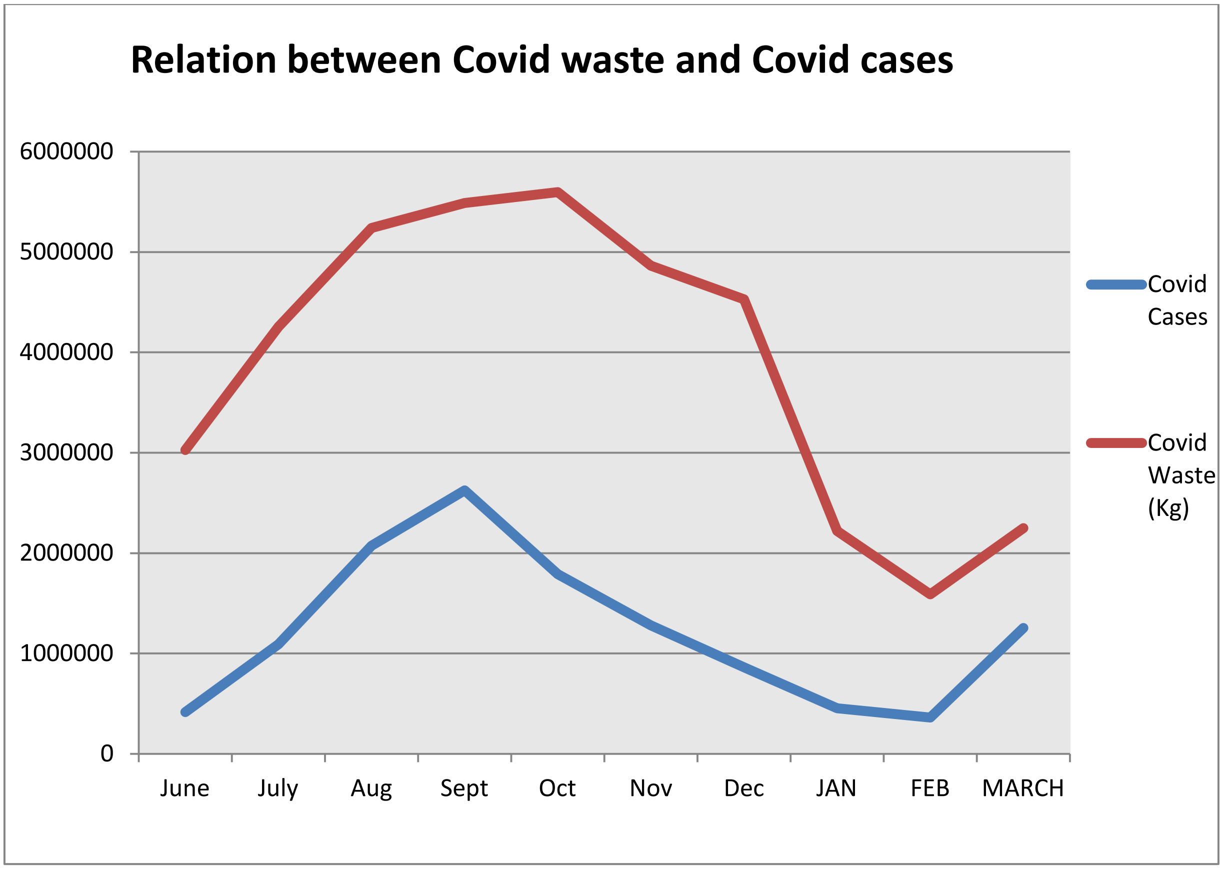

Fig.4.9. Relation between Covid-19 waste and Covid-19 cases

All these show that there is a possibility of Covid-19 virus transmission through Covid-19 waste. This risk is high due to delay and non-treatment at source.

Table. 4.4. Covid-19 Waste generated in India State wise(June to December,2020)

State wise Covid-19 Waste generated from June to December								
	States	June	July	August	September	October	November	December
1	Andaman & Nicobar	0.42	0	0	0.42	0.43	0.42	0.43
2	Andhra Pradesh	165.48	182.81	118.82	112.35	116.09	317.91	328.51
3	Arunachal Pradesh	3.36	3.36	3.8	3.36	3.472	3.36	3.47
4	Assam	28.38	20.68	12.57	62.61	51.74	50.07	23.41
5	Bihar	6.84	20.76	41.54	45.36	44.64	28.08	23.31
6	Chandigarh	29.85	5.65	55.34	43.02	73.19	70.83	73.19
7	Chhattisgarh	11.19	0	13.39	9.3	9.61	9.3	9.61
8	Daman & diu	0	0	0	0.48	2.387	1.08	1.15
9	Dadar & Nagar Haveli	0	0	0	0	0	0	0
10	Delhi	333.42	389.58	296.14	382.5	365.89	385.47	321.32
11	Goa	0.81	0.81	0	15	7.75	5.43	5.39
12	Gujarat	350.79	306.14	360.04	622.89	545.88	423.51	479.57

13	Haryana	75.33	184.18	210.69	278.31	238.45	239.4	209.93
14	Himachal pradesh	3.81	12.5	4.94	25.2	28.11	30.03	48.24
15	Jammu & Kashmir	10.71	9.77	51.77	57.39	59.3	44.82	35.12
16	Jharkhand	0	0	2.59	4.8	4.96	4.8	11.63
17	Karnataka	84	540.28	588.03	168	218.02	210.99	218.02
18	Kerala	141.3	293.32	588.05	494.1	641.98	600.39	542.47
19	Lakshadweep	0.3	0	0	0.3	0.31	0.3	0.31
20	Madhya pradesh	224.58	56.4	106.59	339	308.42	208.65	249.49
21	Maharashtra	524.82	1180	1359	524.82	542.31	609	629.3
22	Manipur	5.13	0.2	2.09	5.13	5.301	5.13	9.27
23	Meghalaya	5.1	1.74	6.34	9.9	12.028	7.65	8.56
24	Mizoram	4.2	0	0	4.2	3.224	3.12	3.22
25	Nagaland	3.6	3.4	3.1	2.85	3.317	1.86	2.29
26	Odisha	31.86	106.63	109.19	134.01	183.46	222.66	125.58
27	Pudducherry	18.63	35.82	41.54	63	58.65	28.74	17.11
28	Punjab	48	35.59	21.19	234.42	149.61	96.51	86.99
29	Rajasthan	177	7.15	50.43	145.08	171.55	141.93	105.93
30	Sikkim	6	0.2	0.3	6	4.22	3.69	2.45
31	Tamil Nadu	312.3	401.29	481.1	543.78	524.18	300.75	251.22
32	Telangana	12.3	10.5	24.04	188.82	144.8	103.89	68.82
33	Tripura	0.45	0	0	0.45	0.46	0.45	0.47
34	Uttarakhand	0.45	0.82	41.85	21.72	108.99	56.76	76.26
35	Uttar Pradesh	210	307.54	408.86	507.15	478.08	316.71	276.46
36	West Bengal	195	136.37	235.12	434.76	486.79	330.84	279.06
	Total	3025.41	4253.46	5238.45	5490.06	5597.169	4864.11	4527.13

Chapter-5
Various Waste Management Methods

5. Various Waste management methods

The MSW waste in India is managed by landfilling, composting, incineration, pyrolysis, gasification which are discussed in detail as:

Landfilling

Sanitary landfilling is characterized as the controlled removal of squanders ashore with biogas recuperation and leachate the board to lessen the adverse consequence on the climate. Unsanitary landfilling, then again, is a more clear and financially savvy choice. for the removal of expanding trash volumes, and is the most successive methodology in non-industrial nations, representing an extreme ecological risk. Studies showed that when contrasted with other waste administration techniques, the effect of landfilling has most noteworthy natural effect. Landfilling turns into the most exceedingly terrible choice when factors including natural effect, wellbeing sway, land disintegration, and groundwater pollution are considered. Created nations, then again, have started to debilitate trash landfilling by severe limitations, squander decrease, and reusing. Landfill leachate is a critical contamination radiated from landfills or dump locales. (Müller et al., 2015) This dirties surface water courses and groundwater springs nearby. As indicated by specialists, landfilling ought to just be utilized for 10–15 percent of absolute rubbish made, and it ought to be the final hotel for networks with a restricted area.

CO2e Emission estimates from landfill sites in 2016			
	Total MSW (tonne/day)	MSW Dumped (in Percent)	CO2e emission (tonne/day
Delhi	9620	50	1764
Mumbai	8600	80	2523
Chennai	5000	80	1467
Bengalore	4200	60	924
Pune	1600	35	205
Indore	700	60	154
Chandigarh	450	60	99

Fig.5.1. CO_2e emission from landfill sites in 2016(Müller et al., 2015)

The various thermo-chemical treatment processes like composting, incineration, pyrolysis etc are a fundamental segment of a reasonable coordinated city strong waste (MSW) the executives framework

Composting

Anaerobic digestion (or bio-methanation) is a strategy for delivering biogas and balancing out slime by microbial decay of natural biodegradable matter without oxygen. The nature of the biogas delivered is dictated by the interaction boundaries and substrate sythesis; typically, the biogas contains 50–75 percent CH_4, 25–50 percent CO_2, and 1–15 percent different gases, (for example, water fume, NH_3, H_2S, thus on)(Surendra et al., 2014). The wet strategy produces more fluid waste and less strong rubbish. The volume of reactor needed for the wet cycle is not exactly that needed for the dry interaction. Beforehand, anaerobic processing was utilized to deal with homegrown sewage, farming waste, natural waste, and animal excrement, yet it is presently generally utilized to recuperate energy from MSW, especially in helpless countries, where squanders have high dampness content (Yap and Nixon, 2015). The suitability of biogas recuperation was examined, and it was found that biogas recuperated utilizing anaerobic absorption innovation is both monetarily and naturally reasonable.

Incineration

Incineration is a waste treatment innovation that includes changing over natural waste materials into debris, pipe gas, and warmth by fire. It has a more prominent temperature and change rate than other biochemical and physicochemical strategies, empowering for the productive treatment of numerous types of strong waste, particularly unsorted remaining rubbish (for example trash that isn't gathered independently and can't be reused in a financially savvy or harmless to the ecosystem way). Their key benefits remember a huge decrease for squander mass (around 70–80 percent) and volume (around 80–90 percent), just as a critical decrease in land use. These innovations incorporate the annihilation of natural impurities like halogenated hydrocarbons, the focus and immobilization of inorganic pollutants, the usage of recyclables from warm buildups like ferrous and non-ferrous metals from base debris and slag, and the decrease of ozone depleting substance discharges from anaerobic decay of natural squanders. Warm treatment plants might change over the energy worth of MSW into different types of energy, including power and cycle heat, which can be utilized in modern offices or for area warming.

Pyrolysis

Pyrolysis is a cutting edge warm treatment. It takes happen at temperatures somewhere in the range of 400 and 800 degrees Celsius without oxygen. The yield and nature of pyrolysis gas, oil, and roast are generally dictated by the warming rate, measure temperature, and home duration(Lombardi et al., 2015), piece of squanders, and molecule size of the waste (Kalyani and Pandey, 2014). Pyrolysis oil, wax, and tar are the fundamental items at lower temperatures (500–550 C), while pyrolysis gases are the principle items at higher temperatures (>700 C). The feedstock for great pyrolysis items ought to be a sure kind of trash (plastic, tire, electronic hardware, electric waste, wood squander, and so forth) Different past research on the pyrolysis of explicit kinds of squanders were distributed, however they zeroed in on the technique instead of the likely monetary utilizations of pyrolysis items. Pyrolysis has as of late collected a great deal of interest for reusing reused tires for oil, wire, carbon dark, and gas recovery(Lombardi et al., 2015). In spite of the fact that unmistakably pyrolysis is viable in treating explicit waste streams, a couple of examination on energy recuperation from MSW utilizing pyrolysis at a business scale have been distributed. Since 1987, a 110-ton-per-day MSW pyrolysis office in Burgau, Germany, has been successfully creating power (Lombardi et al., 2015). Baggio et al. (2008) announced that pyrolysis of MSW for gas creation can be utilized for energy recuperation with a net change proficiency of 28–30% utilizing Gas Turbines.

Gasification

Another warm transformation measure is gasification, which includes changing over natural mixtures into syngas in a controlled climate of oxygen at high temperatures. Syngas is the essential side-effect of the gasification cycle, and it tends to be scorched to create energy. It can likewise be utilized to make synthetic and fluid fuel feedstock(Yap and Nixon, 2015). Most of gasification examines that have been distributed have centered around a homogeneous progression of strong fuel (coal, wood, and so on) and a particular kind of MSW. Despite the fact that gasification is ordinarily used in the coal business, it is currently being inspected as a practical energy recuperation elective for MSW (Arafat and Jijakli, 2013). Panepinto et al. (2014) An aggregate of 100 plants utilizing the gasification way to deal with handle MSW were examined all throughout the planet. In Japan, MSW gasification innovation is generally utilized, with 85 offices in activity starting at 2007. Gasification has been used to deal with MSW at a lower scale in different nations (like the United States, the United Kingdom, Italy, Germany, Norway, and Iceland) (Panepinto et al., 2014). As indicated by reports, the gasification interaction delivers less CO_2 than a comparable limit incinerator. (Murphy and McKeogh, 2004).

Defra (2013) Modern gasification units accompany fenced in areas, which effectively decline the danger of water and soil tainting, as per the paper. Asia has gained huge headway in gasification innovation as of late and can be viewed as quite possibly the most ideal business sectors for gasification innovation, trailed by Europe, Africa, and the United States. (Ouda et al., 2016).

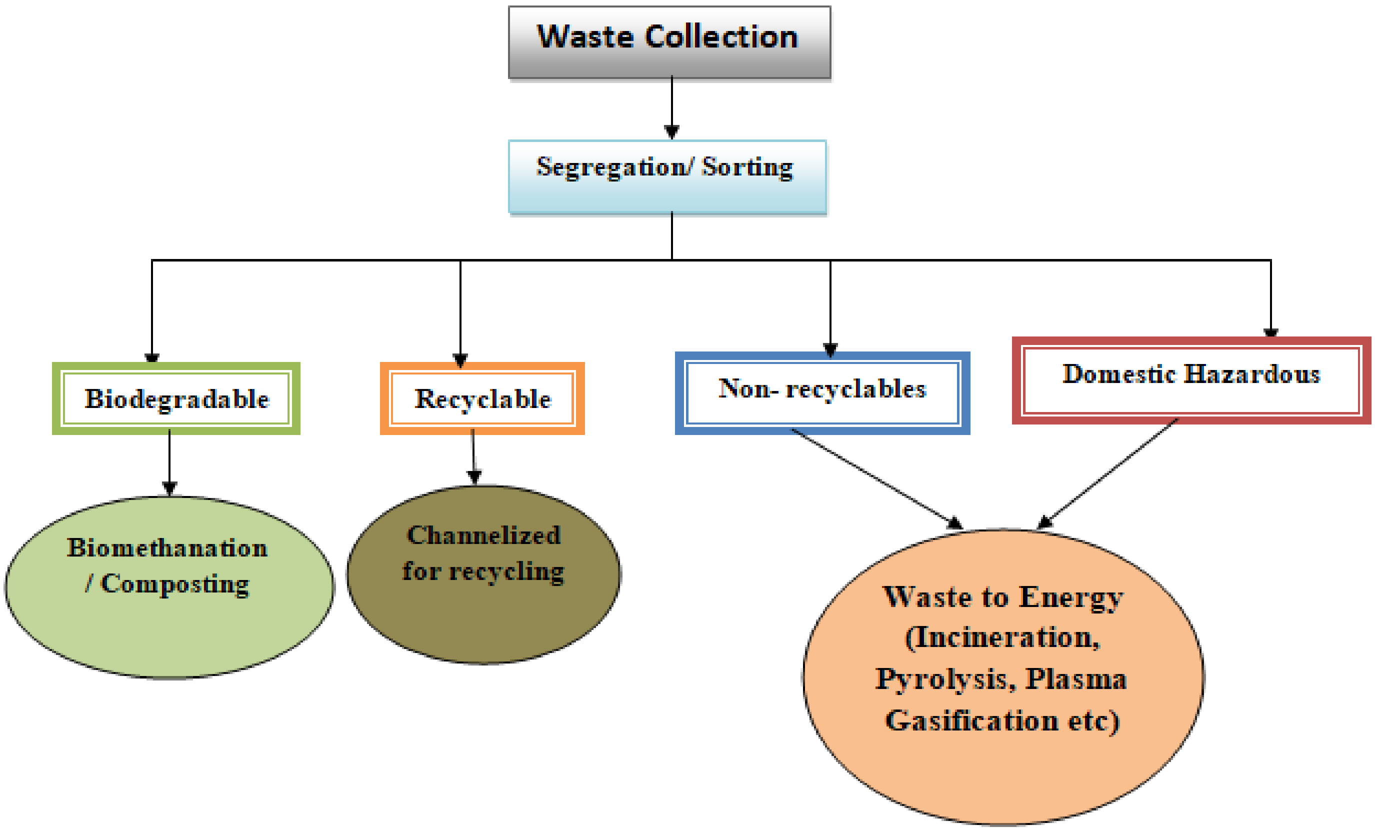

Fig.5.1. Schematic Diagram for Municipal Solid Waste Management in India

The process comparison with respect to to operating condition, environmental impact, cost etc has been shown in table 5.1.

Table 5.1. Comparison of various MSW treatment methods used

	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	-

5.1. BWM waste management

Table5.2. Biomedical waste classification

Category	Type of waste	Color and type of bag to be used	Treatment and disposal options
Yellow	Human tissues, organs, body parts and fetus below the viability period (as per the Medical Termination of Pregnancy Act 1971, amended from time to time)	Yellow-colored non-chlorinated plastic bags	Incineration or plasma pyrolysis or deep Animal anatomical waste burial
	Animal Anatomical Waste : Experimental animal carcasses, body parts, organs, tissues, including the waste generated from animals used in experiments or testing in veterinary hospitals or colleges or animal houses.	Yellow-colored nonchlorinated plastic bags	
	Soiled Waste: Items contaminated with blood, body fluids like dressings, plaster casts, cotton swabs and bags containing residual or discarded blood and blood components		Incineration or plasma pyrolysis or deep burial. In the absence of above facilities, autoclaving or microwave/hydroclaving followed by shredding/mutilation/combination of sterilization and shredding. Treated waste to be sent for energy recovery
	Expired or Discarded Medicines: Pharmaceutical waste like antibiotics, cytotoxic drugs including all items contaminated with cytotoxic drugs along with glass or plastic ampoules, vials etc	Yellow-colored nonchlorinated plastic bags	Expired cytotoxic drugs and items contaminated with cytotoxic drugs to be returned back to the manufacturer or supplier for incineration at temperature >1200° C or to CBMWTF or hazardous waste treatment, storage, and disposal facility for incineration at >1200° C or encapsulation or plasma pyrolysis at 1200° C
	Chemical waste- chemicals used in production of biological and used or discarded disinfactants.	Yellow-colored non-chlorinated plastic bags	Disposed of by incineration or plasma pyrolysis or encapsulation in hazardous waste treatment, storage, and disposal facility.
	Chemical Liquid Waste : Liquid waste generated due to use of chemicals in production of biological and used or discarded disinfectants, Silver X - ray film developing liquid, discarded Formalin, infected secretions, aspirated body fluids , liquid from laboratories an d floor washings, cleaning, house - keeping and disinfecting activities etc.	Separate collection system leading to effluent treatment system	After resource recovery, the chemical liquid waste shall be pretreated before mixing with other waste forms
	Discarded linen, mattresses beddings contaminated with blood or body fluids	Non-chlorinated yellow plastic bags or suitable packing material	Non-chlorinated chemical disinfection followed by incineration or plasma pyrolysis or for energy recovery
	Microbiology, biotechnology, and other clinical laboratory waste	Autoclave safe plastic bags or containers	Pretreat to sterilize with non chlorinated chemicals on-site as NACO or WHO guidelines, thereafter for incineration
Red	Contaminated waste (recyclable)	Red-colored non-chlorinated plastic bags or containers	Autoclaving or microwaving/hydro claving followed by shredding or mutilation or combination of sterilization and shredding. Treated waste to be sent to registered recyclers or for energy recovery or plastics to diesel or fuel oil or for road making
White (Translucent)	Waste sharps including metals	Puncture proof, leak proof, tamper proof containers	Autoclaving or dry heat sterilization followed by shredding or mutilation or encapsulation in metal container or cement concrete; combination of shredding cum autoclaving and sent for final disposal to iron foundries
Blue	Glassware and metallic body implants.	Cardboard boxes with blue-colored	Autoclaving or dry heat sterilization followed by shredding or mutilation or encapsulation in metal container or cement concrete; combination of shredding cum autoclaving and sent for final disposal to iron foundries Blue Glassware Cardboard boxes with blue-colored marking Disinfection or through autoclaving or microwaving or hydroclaving and then sent for recycling

Source: MoEF&CC,2016

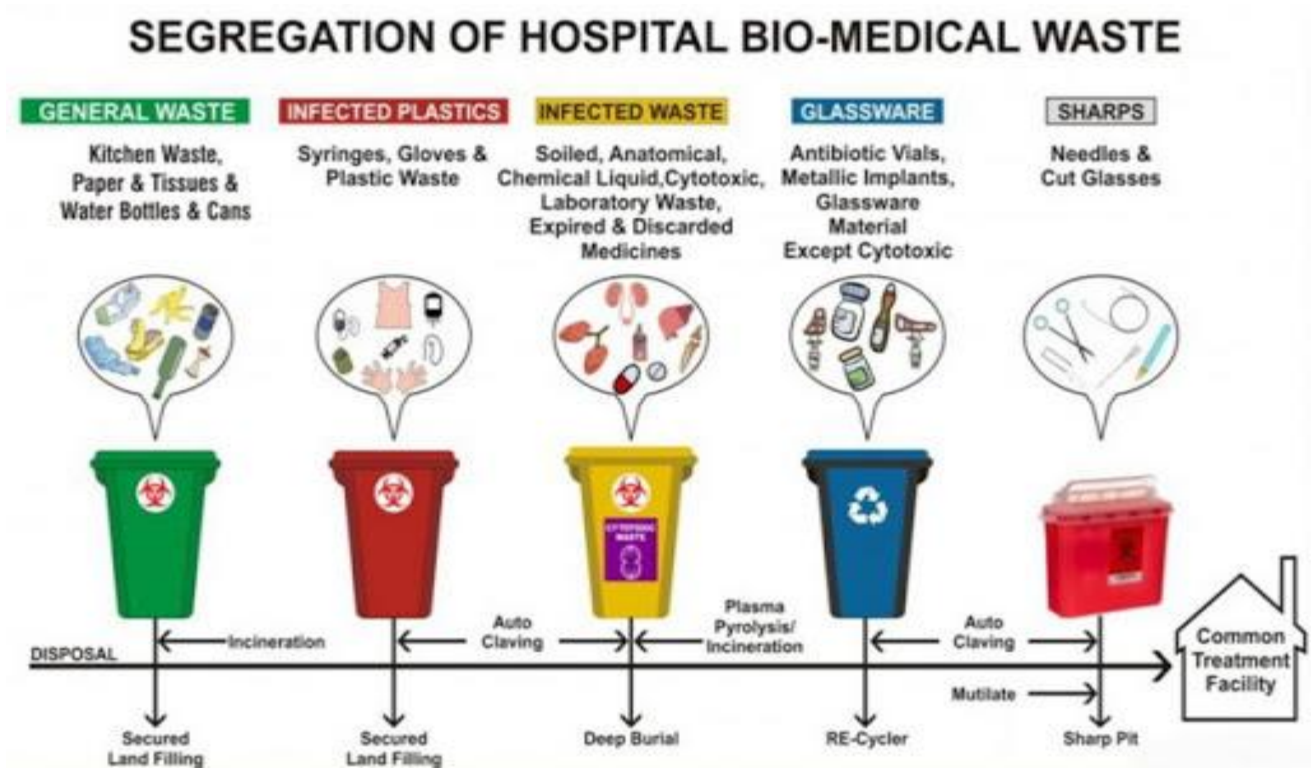

Fig.5.2. Bio-Medical Waste Management and Handling

Incineration, CBWTF, and other procedures are used to treat the BMW. With modest modifications, same procedures are applied to new Covid-19 contagious waste [CPCB,2020, Mohfw,2020]. Because of its communicable nature, the standard biological waste management principle of reduces, recycles, and reuse does not apply to COVID-19 waste. COVID-19 waste classification is the initial step in its treatment (Pichtel, 2005). The classification of BMW trash not only facilitates waste management and minimises the danger of contamination to other waste handlers, but it also reduces the risk of contamination to other waste handlers (Raghuvanshi et.al. 2018). COVID-19-waste should be collected with clearly marked packs in separate bags/bins. Before being transferred from/to the site of origin the bags containing BWm/COVID-19 should be disinfected, sealed in two-layered plastic bags (usually yellow colour). Bio-medical waste can be treated using the CBWTF and other treatment methods. However, these techniques carry a substantial risk of infection transmission. Because of the high waste creation, the Covid-19 waste has placed a greater strain on existing treatment procedures.

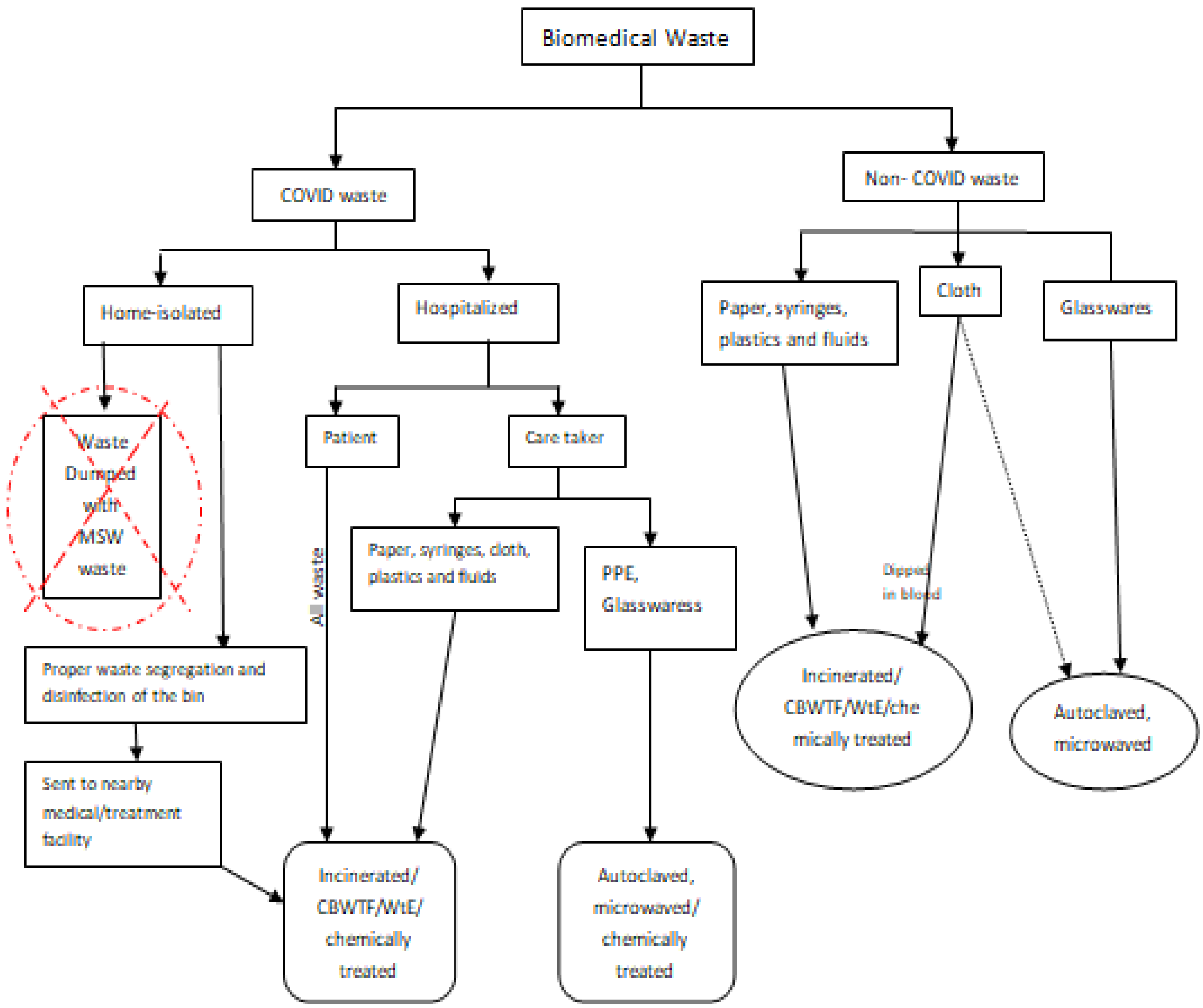

Fig.5.3. BMW and Covid-19 waste treatment methods

The treatment methods involved in treatment of bio-medical waste are incineration, autoclaving, microwaving, pyrolysis, dry heat technique etc (S.A.Hakim et.al 2014).

Autoclaving is a low-heat thermal procedure that involves bringing steam into direct contact with trash in a regulated manner and for a long enough time to disinfect it, as required by the Bio-medical Waste Management Rules. The system should be horizontal in design and especially built for the convenience and safety treatment of biomedical waste. Pre-vacuum-based systems should be favoured over gravity-based systems for best performance. As needed by the BMWM Rules, it should highlight a sealed control board with proficient showcase and recording gadgets for recording imperative parameters like time, temperature, pressure, date, and cluster number.

Hydroclaving is identical to autoclaving, with the exception that the waste is heated indirectly by steam in the outer jacket. During the procedure, the trash is continuously tumbled in the chamber.

Microwaving: Microwaving causes microbial inactivation due to the heat effect of electromagnetic radiation with frequencies ranging from 300 to 300,000 MHz. Microwave heating is a type of intermolecular heating. In the presence of steam, the waste material is heated within**.**

Chemical disinfection: However chemical disinfection or substitutes, as characterized by the BMWM Rules, are a possibility for treating particular kinds of biomedical waste, for example, glass squander, believing the volume and pollution due to the use of synthetic sanitizers for the CBWTF cleaning, compound sterilization for therapy of biomedical waste as a component of a CBWTF might be utilized sparingly or can be stayed away from.

Dry heat sterilization: According to the BMWM Rules, this is an extra alternative for the treatment of waste sharps. Waste sharps are treated in this manner with dry heat (hot air) at a temperature of not less than 1850 C for at least 150 minutes in each cycle (with sterilisation period of 90 minutes). f) Shredder: Shredding is the process of deforming or cutting garbage into smaller pieces in order to render it unidentifiable. It aids in the prevention of BMW Reuse and prove that trash has been cleansed and is safe for disposal.

Sharp pit/ Encapsulation: For treated sharps, a sharp pit or an embodiment facility should be provided in a metal holder or cement (i.e., treatment via autoclaving or dry heat sterilisation followed by shredding or mutilation).

Burn-free technology: Some developed countries have used non-incineration technologies for the disposal of bio-medical waste. Shredding and disinfection by autoclaving/microwaving or chemical treatment are examples of non-incineration technologies. The treated garbage can be disposed of in sanitary landfills or at waste-to-energy plants alongside municipal solid refuse.

5.2. Guidelines for Covid-19 Waste

The Covid-19 waste is likewise burnt at a very high temperature, resulting in full waste destruction. The incineration procedure is extremely effective in completely destroying Covid-19 waste and can reduce waste by up to 90%. The incineration process uses a lot of electricity, and it's also expensive to set up and run. During the incineration and post-combustion cooling operations, waste materials dissociate and recombine, resulting in hazardous PIC particles. Metals are not lost in the process; instead, they are released into the atmosphere, causing serious health concerns. Dioxins are a group of 75 pollutants that are produced as a by-product of waste combustion incineration with another category of toxins known as furans. These poisons can accumulate in fatty tissues and travel up the food chain, posing a risk of bioaccumulation and biomagnification. The primary source of dioxin gas in the environment is the combustion of polyvinyl chloride-based medical devices (PVC). The autoclave method and dry heat technique are used to treat hospital glassware. Microwaves are also used to treat hospital waste, although they are expensive and prone to recontamination. Autoclaves and microwaves are normally used only for sterilisation and disinfection, with the sterilised material being disposed of with municipal waste or burned in incinerators. The amount of trash generated remains constant because these procedures are usually utilised for disinfection (sterilisation). Because microwave technology is reliant on radiation, it needs a considerable investment as well as the correct set of circumstances (Mehta, et. Al. 2018). Employees frequently come into contact with a polluted shredder. Because autoclaves employ high-temperature steam and microwaves release radiation that can cause skin disorders or mutations, both systems require professional labour. The chemical treatment is done by use of chemicals generally chlorine, peroxide, ozone etc. this technique is also used for disinfection purpose only not ultimate disposal.

Table 5.3. BMW treatment processes comparison

	Incineration	Pyrolysis	Microwave	Chemical	Dry heat technique
Process	Controlled Combustion in presence of oxygen under high temperature	Combustion in presence of limited oxygen supply	Disinfection by moist heat and steam generated by microwave energy	crushed hospital wastes are mixed with chemical disinfectants (such as sodium hypochlorite, calcium hypochlorite, chlorine dioxide, etc.) and stayed for a sufficient time	Hot air is directed in a way that causes the waste particles to rotate turbulently around a vertical axis in a torroidal mixing action
Temperature	800°C -1200°C	540°C -830°C	177 °C -540 °C	-	>100 °C
Mass reduction (w/w%)	90%	90%	10-15%	0	20-25%
Strengths	Simple operation, complete destruction of BMW/COVID-19-waste	Complete destruction of toxins like furan and dioxins	Low action temperature saves energy, less pollutant release without gaseous emission	Rapid and stable performance, broad sterilization spectrum	Polymeric material compatibility with reprocessing possibility
Weakness	Energy-intensive, high capex, release of toxins and solid residual waste	High investment costs and strict demand for heat value of wastes	Relative narrow spectrum of disinfection, sometimes needs to be applied with autoclaving	Does not reduce volume and mass of BMW	Decontamination works through all the layers of trapped virus in the particles is unanswered
Environmental impacts	dioxin, furans, and bottom ash	Not known and taken as a safe technology	Complex impact factors of disinfection	Anthropogenic aerosols formed can penetrate alveoli upon inhalation, absorbance of atomized disinfectants into skin causes cancer	Decontamination of all layers of trapped virus in particles is questionable

Chapter-6

Plasma based Waste Management Technology

6. Plasma based Waste Management Technology

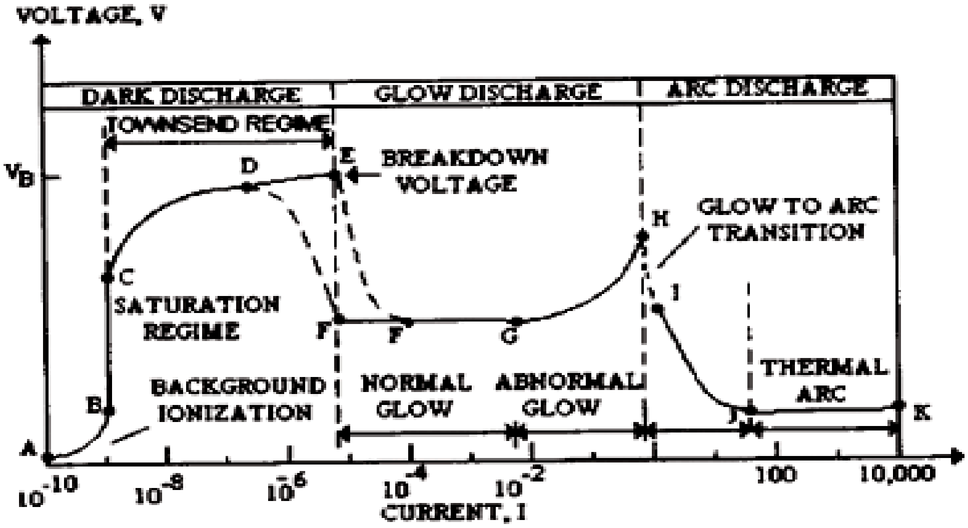

Figure 2. Universal voltage-current curve characteristic of the DC low-pressure electrical discharge tube.

Fig.6.1. Universal voltage current arc characteristic of the DC low-pressure electrical discharge tube.

Plasma is the most common form of matter in the world; it is proven by a quasi-neutral gas of charged and neutral particles which has a group behavior. When ordinary stuff is heated to temperatures above a few thousand degrees Celsius, electrically charged gases or fluids arise. The electrical communications of the particles and electrons, as well as the presence of an attracting field, have a substantial impact on them. Plasma VI has a similar appearance to an electrical discharge tube. A high nonlinear Voltage-Current arc of current (I) is observed on raising the voltage V as shown in fig 6.1 . It can be easily categorized in the three major regimes: Dark Discharge, the Glow Discharge and the Arc Discharge. The utilization of high current thickness is sufficient to heat the cathode to radiance, then, at that point an irregular glow-to-arc change locale shows up. The arc regime system is comprised of three locales: the glow to arc change, the non-thermal arc, and the thermal arcs. The thermal arcs are framed at higher pressing factors and higher gas temperatures than non-warm arcs; be that as it may, non-warm arcs might exist at environmental pressing factor. The electron thickness in warm arcs is higher than in non-warm circular segments. In non-warm arcs, low emanation arcs require thermionic outflows from cathodes, while in warm circular segments, extreme focus arcs normally work in field discharges.

The basic concept of plasma generation is similar to vacuum tube DC electrical discharge, in which a large amount of electrical energy is applied to a gas at a specific temperature and pressure, which tends to excite and ionise it, generating electrons that collide with subsequent atoms in an inelastic manner, resulting in the generation of more ions and electrons. This process is self-sustaining as long as a constant supply of energy is applied in a thermodynamically balanced way. Due to the high temperature, a considerable electrical resistance is created throughout the system. Plasma is created by using energy produced by electric frequency releases flowing to the Optical Reach in the order of 1015°C from direct current (DC). Three kinds of plasma, Thermal plasma, cold plasma and warm plasma may be sorted.

- **Thermal plasma**: Thermal plasma is a form of plasma similar to fusion plasma that is found in stars with temperatures ranging from 4000 to 20,000 K. It can only be achieved if the energy transfer from electrons to gas heating is quick, resulting in thermal equilibrium. Thermal equilibrium implies that all plasma species, including electrons, atoms, ions, and neutral species, have the same temperature.
- **Cold plasma**: The second form of plasma, often known as cold plasma, is a non-harmony plasma with low energy levels because of the sluggish energy move from electrons to gas warming. The energy level in the plasma is low enough for the particles to quickly cool to surrounding temperatures. At atmospheric pressure, corona discharges, whether AC, DC, or pulsed, can produce this type of plasma.
- **Warm Plasma**: Warm plasma, the third form of plasma, exhibits high translational temperatures of roughly 2000 K, although being much lower than heat plasmas. Through non-equilibrium discharges, this plasma releases energy into the atmosphere. Microwave plasmas are one type of plasma with physical features that allow for the generation of a stable condition under a variety of external conditions.

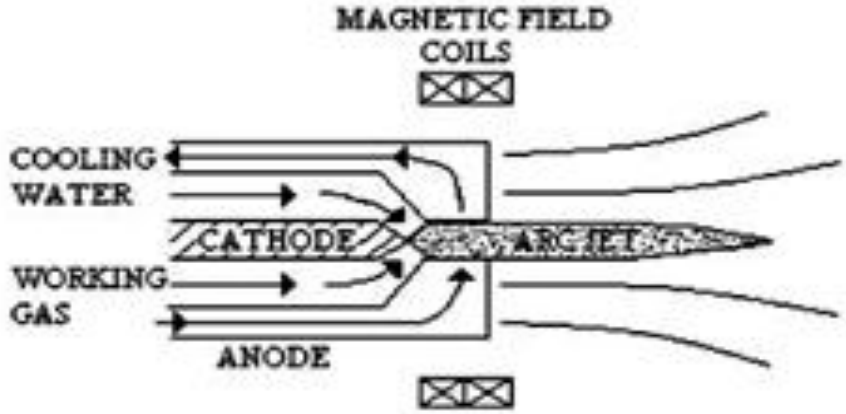

Figure 6. The axe symmetric, non-transferred, unmagnetized arc jet or plasma torch. An arc is struck between the cathode and the coaxial anode, and working gas is heated by passage through the arc region.

Fig.6.2. Plasma arc/ torch between cathode and coaxial anode.

Thermal plasma can be produced in an assortment of ways [A. Bogaerts et al.], anyway arcs produced plasma and Radio Frequency inductively coupled discharges are the most common. High Direct Current is used across two terminals to set up a potential difference across the input gas in Arc created plasma. The gas is compelled to go through the little region between the two anodes that supply the energy, causing an electrical breakdown that prompts plasma creation. The plasma leaves the light through a round opening in one of the cathodes, most generally the anode (non-moved arc generators). The subsequent plasma arc is unsteady. Subsequently, the circular segment is settled utilizing an outer attractive field. Restricting the stream pace of the plasma gas can likewise be utilized to balance out the circular segment. DC plasma circular segment generators are planned in an assortment of ways, including terminal nature and anode detachment from the cathode. It's typically a directing material, similar to graphite, that is additionally unmanageable and shouldn't be cooled with water. It can have an opening in it to allow the plasma to gas to go through, or the gas can be compelled to enter through the cathode from an external perspective, directed by a restricted wall [Fig.6.2]. Various rod electrodes might be utilized in transferred arc reactors to create a plasma arc. Non-transferred DC arc torches are well known in view of their high-temperature plasma arcs and prevalent reactant-plasma blending. sputtering happens when released particles and ions from the plasma gas crash into the cathode surface, causing the arrival of auxiliary electrons and a few molecules from the cathode, which then, at that point settle along the round anode surface or pass through the opening, contaminating the reactant. Because of this occurrence, cathodes have a short life duration and must be replaced on a regular basis, increasing maintenance costs and frequency. Furthermore, cooling water, which is required for steady arc operation, wastes more than half of the electrical energy put into thermal plasma. Metallic electrodes, on the other hand, are easily corroded or melted. This is the major flaw that causes thermal plasma's energy efficiency to be low. The energy required to generate the plasma is provided by the RF induction coils, allowing the feed to be injected directly through the plasma region. RF inductively coupled thermal plasma discharges are becoming more popular because their design prevents any contact between the plasma gas and the electrodes.

6.1. Application of Plasma Technology for BMW

The most practical answer to the oncoming and rising waste management dilemma, ranging from home garbage to other hazardous wastes such as Bio-medical wastes, is thermal plasma. The essence of thermal plasma treatment is based on its high temperature, strong, and nonionizing radiation. The plasma arc has a higher energy density than a normal combustion flame, allowing it to handle a wide range of waste types, including regular solid MSWs, liquids such as urine, and toxic gases. Thermal plasma's high temperature and high energy density allow for a high throughput in a small-scale waste treatment reactor. The strong plasma heat gradient in these reactors enables quenching, which is beneficial in trying to recover goods from waste. The high flux density generated by the plasma at the reactor border allows for a quick transition to steady state, lowering start-up and shutdown periods significantly. The heat source is generated without the need of oxidants, and only a little amount of gas is created, making the entire process considerably more manageable. It is also cost-effective and environmentally friendly, as greenhouse gas emissions are far lower than acceptable levels. Plasma can be used to treat MSW in two ways: plasma pyrolysis and plasma gasification. Plasma gasification is the term used for the generation of extremely high temperatures, particularly for high efficiency gasification by a series of techniques that employ plasma torches or plasmas arcs. Plasma pyrolysis is the gasification of any feed in a low oxygen ambient, whereas plasma gasification requires the addition of only a little amount of oxygen and steam. There is no combustion in either process because plasma is the primary source of heat. The products of traditional gasification systems are comparable to those created in the plasma pyrolyse, however plasma gassing/pyrolysis produced syngas are cleaner, free of large amounts of sudden soot.

In actuality, harmful gases like dioxins may contaminate the syn gas, which must be washed out and disposed of in some way, while the rocky solid may also contain contaminated material. Syngas can be used for electrical power, methanol, or fluid energizes like fly fuel, diesel, and synthetic gas generation, contingent upon provincial financial matters. Plasma gasification isn't to be mistaken for incineration, which is the way toward consuming waste to create debris and produce ozone harming substances. It's additionally unmistakable from gasification, which has countless establishments today delivering syn gas to make polymers for the plastics area. Plasma gasification for MSW would not need material arranging, would kill the requirement for landfills, would lessen truck traffic on our roadways, and would be monetarily manageable. The key benefit of the pyrolysis interaction is that the metallic particles don't dissipate, as they do in ignition, when oxygen is utilized to shape metal oxide, which is deadly to the cycle. Pyrolysis can cause thermal cracking, transforming metallic pieces into vitreous form, which can then be collected as useful by-products using the density difference method.

Plasma gasification is a thermo-chemical process, and the plasma furnace is the heart of it. Several chemical changes take occur within the plasma furnace, as defined by the following formulas:

$$C(s) + H_2O = CO + H_2$$ [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].

Plasma gasification involves introducing feedstock (trash) into a vessel with extremely high heat (2,000 degrees F) capable of breaking all organic chemical bonds and converting all trash to fundamental elements, including plastic, paper, glass, yard waste, food, dirt, and so on. Metals are melted and recovered as a result of the heat.

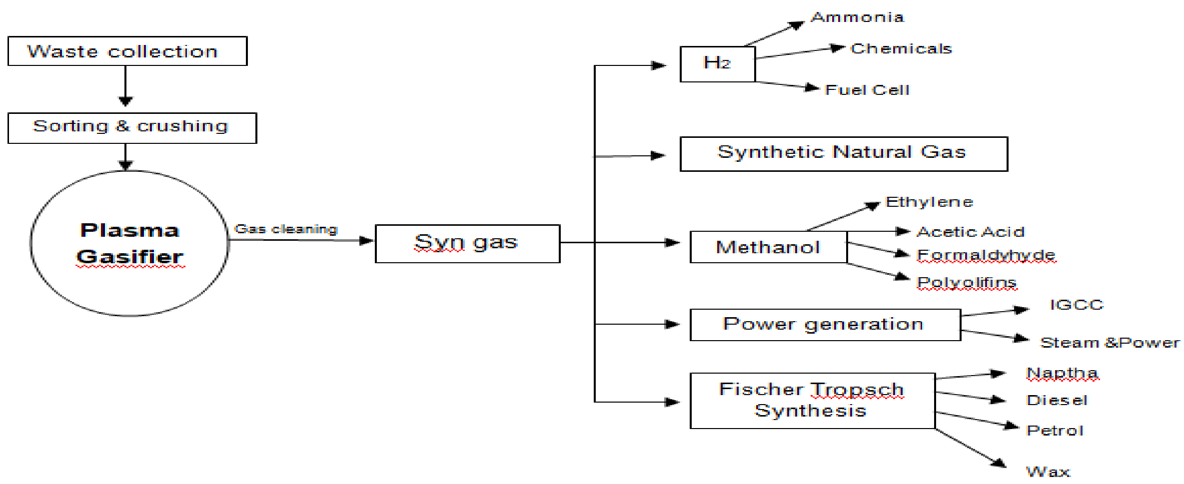

Fig.6.3. Products from Plasma Gasification process

6.2. Scope of Covid-19 waste Management

The large amount of Covid-19 waste and its disposal is becoming a new problem for the society as it requires space and there is a risk factor involved with the movement of such waste as it is infectious so Plasma Gasification can be used to deal with such waste. The plasma gasification plant heats the waste to temperatures ranging from 1000 to 15,000°C (1800–27,000°F), with the average being in the centre of that range, melting the waste and converting it into vapour (Nema. Et. Al. 2002). The end product is synthetic gas (syngas), which is mainly composed of carbon monoxide and hydrogen with a small amount of carbon dioxide and hydrochloric acid, as well as vitrified slag, which includes the liquid form of all inorganic components present in the MSW feed, as well as any residual toxic components in inert form. There is no production of dioxins and furans in the process and the problem of ash disposal is also solved with this process as it dissociates matter into atomic form and return back to the nature. The syngas can be removed and combusted to produce energy (certainly for powering the plasma arc), while the "verified" (vertical) stony solid can be used as a complement (for road building and other construction). In Covid-19 waste management plasma gasification technologies do not need handling of materials, remove waste disposal requirements, minimise road traffic from long-haul transportation and are financially feasible. (Kumar. M et.al, 2020).

Chapter-7

Micro Plasma Treatment plant for BMW: a model

7. Micro plasma BMW treatment plant: a model

It is clear that plasma based waste treatment has high Covid-19 waste treatment capability, but less popular due to its large size and involves high capital investment. Miniaturization of plant can help in this regards, like work of oven into a plasma reactor. Such a micro plasma gasification facility inside the hospital premises not only treat highly infectious Covid-19 waste, but also limit the movement of any type of hazardous waste produced from the hospitals as shown in fig.7.1.

Layout

The hospital has been divided in two compartments one portion of the hospital for Covid-19 patients and other portion for the regular activities of the hospital. Both portions would have separate entries and exits to have least contact among the patients and the waste generated. The micro plasma facility can be installed underground or adjacent to the ICU (Covid-19) ward so that the highly infectious waste can be disposed off immediately. The Covid-19 testing will be adjacent to the entry gate of the hospital followed by isolation ward and at the corner Intensive Care Unit (ICU) for serious patients . The ICU ward would have one way directly towards the entry of the treatment facility. The waste generated from testing facility and isolation ward will be sent to treatment facility through ICU so that chances of spread of the infection can be reduced. If the waste from ICU is taken through isolation ward and testing ward, the highly infected waste will infect other materials in nearby surrounding severely. The waste from other compartment of hospital which is highly infectious such as human anatomical waste, syringes etc. can also be brought to this facility for its treatment.

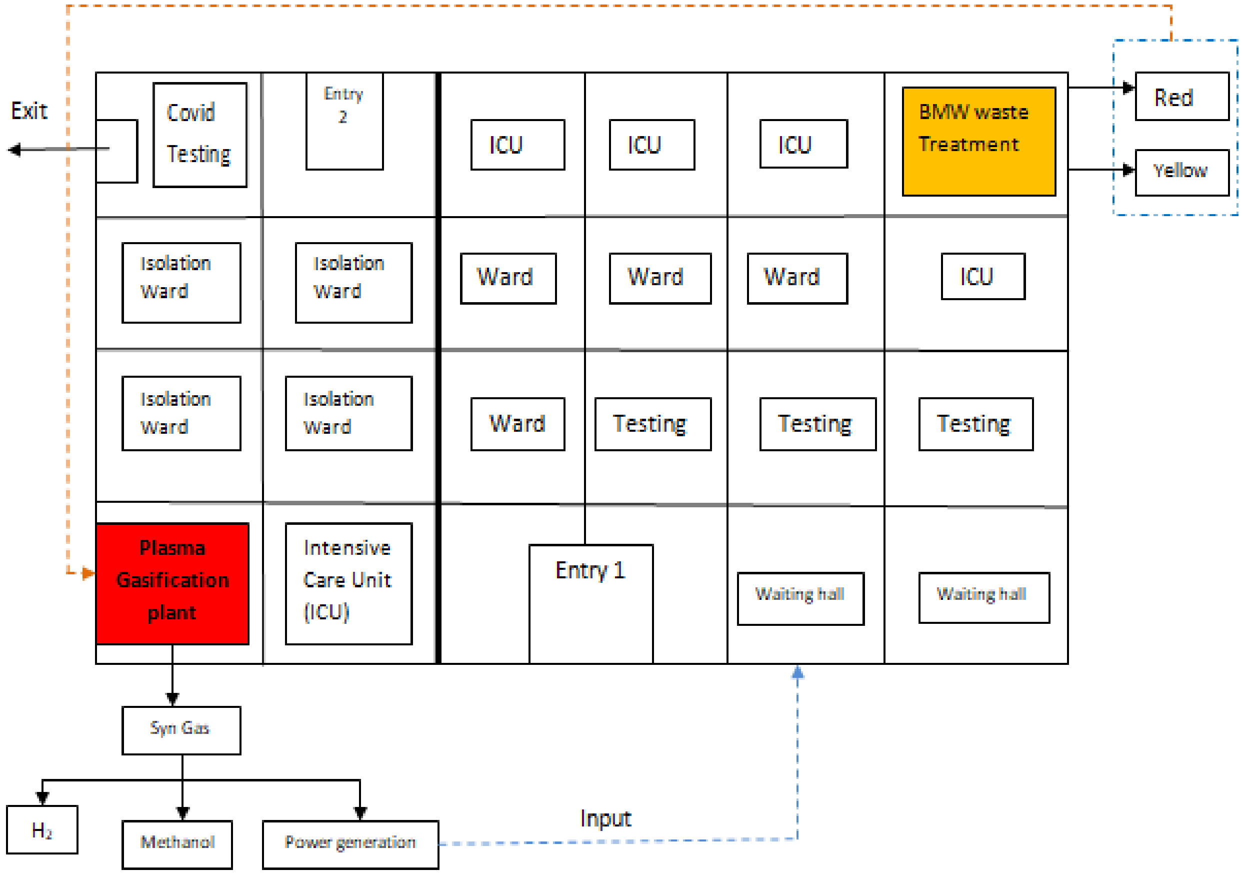

Fig.7.1. Plan layout for Covid-19 waste management in hospitals

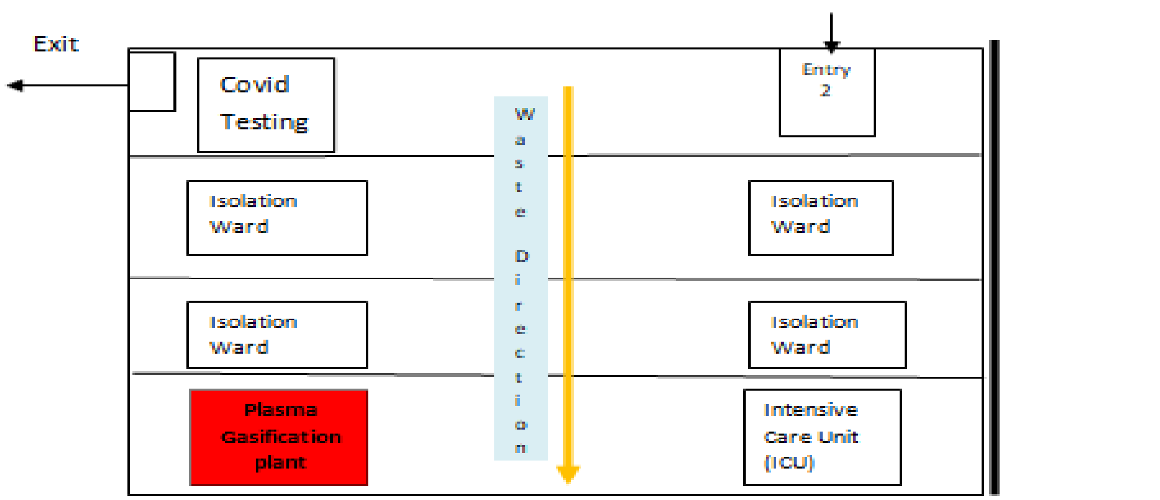

Fig.7.2. Covid-19 Waste movement direction in Covid-19 dedicated portion

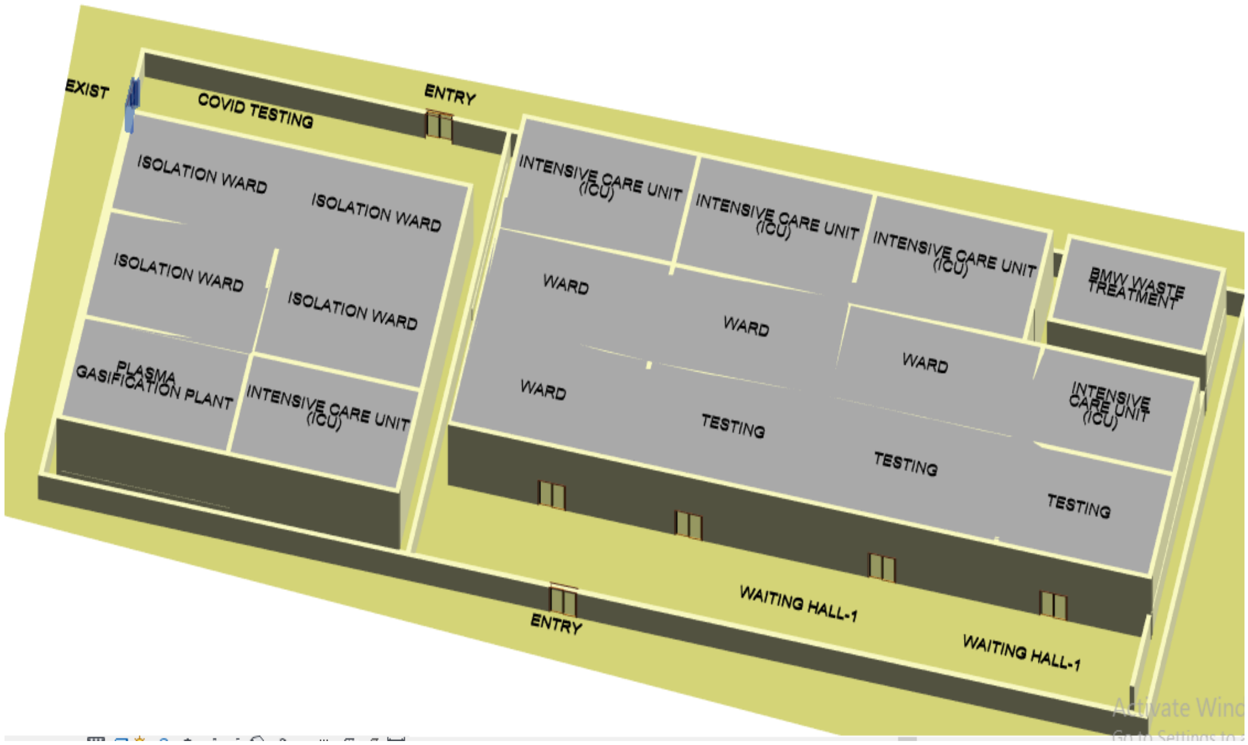

Fig.7.3. 3-D Layout of Hospitals for Covid-19 waste management and plasma facility.

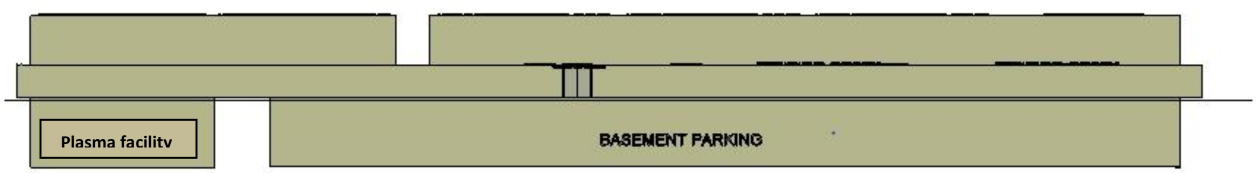

Fig.7.4. Front view of Covid-19 Waste management in hospitals and plasma facility

Chapter-8

Conclusion & Recommendation

8. Conclusion and recommendations

The rate of waste generation is very high and will keep on increasing with increase in population. The quantity of waste is not a challenge for management authorities but the change in type of waste is becoming a problem. The modern waste such as BMW, electronic waste etc is a major challenge for authorities to deal with. The traditional waste management technologies can deal with wastes but with some limitations. The traditional waste management methods has shortcomings of space, time and spread of infection so there is need for finding new approaches to deal with the changing waste type and risk of infection.

The study shows that land disposal method of waste management is practiced in most of the part of the world, some countries like Japan and Singapore incinerate their most of the waste rather than simply landfilling. Countries like Australia and Bangladesh manage more than 95% of waste by land filling method. In India heat treatment method of waste management is relatively new so more than 60% of waste is managed by landfilling method, 20% of waste is composted and 10% of waste is treated using modern techniques.

There is a lack of knowledge among hospital staff and waste management people in proper sorting and segregation of hospital waste. Only around 25% of Bio-medical waste is hazardous in nature which needs to be handled carefully and which require proper treatment. Other 70-75 % of waste can be recycled after treatment using microwave method, sterilizing, autoclaving etc. but it is not practiced in India, most of the Bio-medical waste is sent to the CBWTF for disposal and resource recovery is not practiced which poses extra load on natural resources and treatment facility. Small clinics or un-authorized medical facilities in small area dump their biomedical waste with regular waste which harms waste handlers and rag pickers. This waste also causes epidemic and other related diseases. The bio-medical waste requires proper treatment and hence it should be sent to authorized/registered treatment facility but it is not in practice. There are unauthorized firms which collects BMW waste and treat it in unscientific way in residential area. The discharge from these units is channelled into public sewers which pollutes water and adds metal and other chemicals to it.

Waste management plays an important role in prevention and control of corona virus as it can travel through various modes and can sustain in different temperature ranges alongwith a good survival period without any host. So the waste generated in the treatment of Covid-19 patient has to be managed properly and immediately at the source itself. If the waste is treated on the spot there will be less chances of transmission. Plasma gasification is a modern technology to treat all type of waste including hazardous waste, bio-medical waste etc. It can be the solution for Covid-19 waste related problems and treat waste in an environment friendly way. Though the cost of plasma gasification is comparatively high than the traditional technologies but if the cost to benefit ratio is considered, it is better than other technologies. In the long run, plasma technology is sustainable, it not only treat waste but also reduces load on the landfills which are beyond their capacity and reduces traffic on roads from waste carrying trucks.

The various waste to energy (WtE) methodologies has developed from combustion, gasification, incineration to plasma technology (Edbertho.et.al. 2004, laura.et.al.2009). 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 (3iNetwork. 2009). Reusing and re-utilizing waste are monetarily appealing alternatives because of the far and wide assortment because major portion of waste management budget is being utilized in collection and transportation of the waste[Hargreaves,2008,Leena,2014]. These utilization set waste as resources and help as a key to circular economy. Consequently, boundaries like the speculation, the return time frame and the financial income comprise difficulties to survive to carry out this naturally good procedure. 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, pyrolysis etc. These are thermal conversion methodologies with the benefit of creating leftover measures of sub-items like ash and gaseous emissions These help in prevention of hazardous emissions such as NOx, SOx etc. Such heating produces a synthetic gaseous stream (syngas), which can in this manner be utilized to deliver a variety of items, for example, fuels, power and chemicals. The efficiency to reduce environmental harm of such methodologies depends on various factor such as input materials, temperature, pressure and The processed waste's chemical value. Day-by-day, plasma gasification is a more pleasant approach which provides the right solution, as it combines the benefits of normal thermal conversion methods with a high-performance syngas purification phase. This not only decreases gas emissions, but also provides a product of economic worth.

The micro plasma gasification plant solves the today’s 3 main problems i.e. quantity of waste generated, risk of infection and waste/residue management. Alongwith resolving these issues, the by-products from the plasma treatment will generate revenue and reduces the overall cost involved in the process. The syn gas produced from the plasma gasification treatment plant can be used to produce various products such as H_2, methanol, power generation etc(Kumar.et.al. 2020). The produced energy can be utilized in the hospital and will ultimately reduce the cost of the technology. The treatment of Covid-19 waste with plasma gasification technique gives natural advantages as well as monetary and social advantages by setting out work open doors and financial exercises. Plasma gasification changes the materials into new items, which are utilized straightforwardly or in the assembling of different items. The items can be sold in the market to create income.

Recommendations:

- Places with public gathering should be avoided and social distance should be followed.
- Public awareness should be made for significance of Mask and continuous hand sanitization.
- People should move out of their houses only when it is urgent otherwise it should be avoided.
- As vaccines have been developed, everyone should get vaccinated as it is safe.
- PPE should be mandatory for the people dealing with Covid-19 waste to protect them from infection.
- Covid-19 waste is highly contagious disease so it should be stored with care and bags should be sealed and disinfected.
- The Covid-19 waste in hospitals /medical facilities has greatest potential of carrying virus with it so the waste should be treated at source itself.
- Government should encourage micro plasma based treatment facility in bigger hospitals to treat Covid-19 waste.
- Waste management authorities should ensure the compliance of healthcare facilities to the BMW rules 2016.

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Appendix

Published Papers

Waste Management By Waste to Energy Initiatives in India

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3 authors:

Mukesh Kumar
University of Delhi
47 PUBLICATIONS **25** CITATIONS

S. K. Singh
Delhi Technological University
152 PUBLICATIONS **1,361** CITATIONS

Sandeep Kumar
Delhi Technological University
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WASTE MANAGEMENT BY "WASTE TO ENERGY" INITIATIVES IN INDIA

M. Kumar[1+]
S. Kumar[2]
S.K. Singh[3]

[1]*Assistant Professor, Dept. of Physics, SSNC, University of Delhi, Delhi, India.*
Email: physics.ssn@gmail.com Tel: 919212711976
[2]*Research Scholar, Dept. of Environmental Engineering, Delhi Technological University, Delhi, India.*
Email: sandeepkumar200393@gmail.com Tel: 918860351400
[3]*Professor and Head, Dept. of Environmental Engineering, Delhi Technological University, Delhi, India.*
Email: sksinghdce@gmail.com Tel: 919891599903

(+ Corresponding author)

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ABSTRACT

This century is known for exponentially growing population and development but with huge waste production. The waste produced requires land, labour and capital to for treatment and disposal of such huge amount of waste. In India, people throw or consider it as waste after single use so Indian waste can be good resource for recovery of various products. The waste produced is difficult to manage using conventional methods and is ever increasing, blocking essential land that has become an expensive commodity in today's world. This work explores the current practices of the various waste management initiatives and a critical assessment of traditional waste to energy procedure adopted in India. It gives an overview of the various waste management systems in India. Suggestions for improving the health of society, waste management processes, process performance, environmental assessment parameters to plasma gasification,-an alternate waste to energy has been also discussed. Recommendation has been made for the micro-waste plant to solve the waste challenges.

Contribution/Originality: The main contribution of the paper is to assess waste management in India and certain waste emerging innovations –Waste to Energy, which are technically applicable and relevant. It also addresses how the use of advanced waste technologies like plasma can be a way of achieving a circular economy as well as less environmental impact.

1. INTRODUCTION

Energy is one of the foods for technical or economic development of human beings. Rapid increase in population has resulted in huge demands for energy to for material production. Such thrust for energy and to recover more energy requires technological exploitation of energy resources (Ramos & Rouboa, 2020; Young, 2010). The materials byproducts are related to waste, an inevitable by-product of industrial production. The exponentially growing population has increased the waste production to many fold. Although waste is shown to be a non-essential qualitative component of industrial production, the quantitative scope of waste can vary according to the degree of (in)efficiency with which these processes are operated within certain limits. Over the years, the invention of new products, innovations and facilities has altered the quantity and quality of waste. Waste characteristics do not only depend on income, culture and geography but also on a society's economy and situations like disasters that affect that economy (Ionescu et al., 2013; Kumar, Khare, & Alappat, 2002; Kumar, 2014; Kumar,

Kumar, & Singh, 2020; Kumar & Samadder, 2017; Leena, Sunderesan, & Renu, 2014; Rawat, Kaalva, Rathore, Gokak, & Bhargava, 2016; Vats & Singh, 2014; Vats & Singh, 2014).

Table-1. MSW waste estimate with population.

Year	Population (in million)	Total waste generation (million MT/year)(@0.4kg/capita/day)	Total waste generation (million MT/year) (@0.6kg/capita/day)
2015	1310.15	191.2819	286.9229
2020	1381.59	201.7121	302.5682
2025	1450.52	211.7759	317.6639
2030	1503.64	219.5314	329.2972
2035	1553.723	226.8436	340.2653
2040	1592.69	232.5327	348.7991
2045	1620.61	236.6091	354.9136
2050	1639.17	239.3188	358.9782

Note: *population data from worldometer web.

Waste challenges in metropolitan centers include the growing challenge of acquiring expensive land for disposal, producing emissions from waste treatment and disposal, etc (Sharma & Shah, 2005; Vats & Singh, 2014). The disposal of waste has caused resource depletion and the huge cost involved in waste processing and transportation.

Established processes for the collection, transport and treatment of solid waste are mired in confusion in India. Uncontrolled waste disposal has created overflowing landfills on the outskirts of neighborhoods, which are not only very difficult to retrieve due to haphazard dumping practices, but can have significant environmental effects in terms of water contamination, land degradation and air pollution that lead to global warming. Environmental degradation is taking place and organizations that are responsible for environmental management are facing many problems and challenges. Uncontrolled waste disposal and unsustainable waste management not solely harm the atmosphere, but conjointly have an effect on human health (Central Pollution Control Board (CPCB), 2004; Jha, Singh, Singh, & Gupta, 2011; Kumar & Samadder, 2017). The new scheme relies on the storage and transport of mainly mixed, unsegregated waste.

The 5R solution - Recycling, Reduce, Reuse, Refuse, Recover, Residual Management with sustainable disposal of residual waste in science-based landfills is grossly ignored (Abhishek & Mukherjee, 2019; Alam & Ahmade, 2013; Anubhav, Abhishek, & Durgesh, 2012; Cleary, 2009; Kumar et al., 2017; Nandan, Yadav, Baksi, & Bose, 2017; Otitoju & Seng, 2014; Srinivas, 2007; Sudha, 2008; UN, 2000; World Energy Council Report, 2013; Young, 2010). This work explores the solid waste production status and its environmental and financial impact on Indian cities. This study also analyses the growing number of municipal solid waste (Kumar et al., 2016; Sudha, 2008; World Energy Council Report, 2013) the changing nature of municipal solid waste, from biodegradable waste, dry waste to the increasing volume of plastic in the waste (Cleary, 2009; Devi & Satyanarayana, 2001; Hargreaves, Adl, & Warman, 2008; Indo-UK Seminar Report, 2015 ; Jha et al., 2011; Kumar & Samadder, 2017).

This work also presents the sources of waste-to- energy / energy-from-waste conversion technology for the solid waste sector. Laws for sustainable solid waste disposal have already been set in motion, but a big obstacle is the need to plan and maintain the scheme and ensure implementation of the rules (Sharma & Shah, 2005; Vats & Singh, 2014).

In addition to providing some mitigation options to respond to the growing problem, current governments recommend publicly-engaged frameworks to ensure that the framework is financially sustainable. There are many cleaner technologies for dealing with waste but lack of knowledge and public awareness makes waste management a menace. Public participation is required to deal with the generated waste at source itself.

2. MUNICIPAL SOLID WASTE IN INDIAN CONTEXT

India, the second most populated country in the world and one of the fastest-growing economies, is experiencing unprecedented growth in its industrial sector and is undergoing rapid urbanization. The population of India is approximately 1.3 billion and experts believe that each day a single person is generating 450 grams of waste (Central Pollution Control Board (CPCB), 2000, 2004; Kumar et al., 2016).

Current rate of municipal waste projection as per population growth is shown in Table 1. The study predicts that MSW generation will reach 219- 330 million MT/year by 2030 and 240-358 million MT/year by 2050. Much variability of per capita waste generation is found in accordance with the size and class of the cities. As per CPCB report, in 2012, 1,27,486 tons per day of MSW is being produced from household activities and other commercial & institutional activities (Abhishek & Mukherjee, 2019; Kumar et al., 2016; World Energy Council Report, 2013).

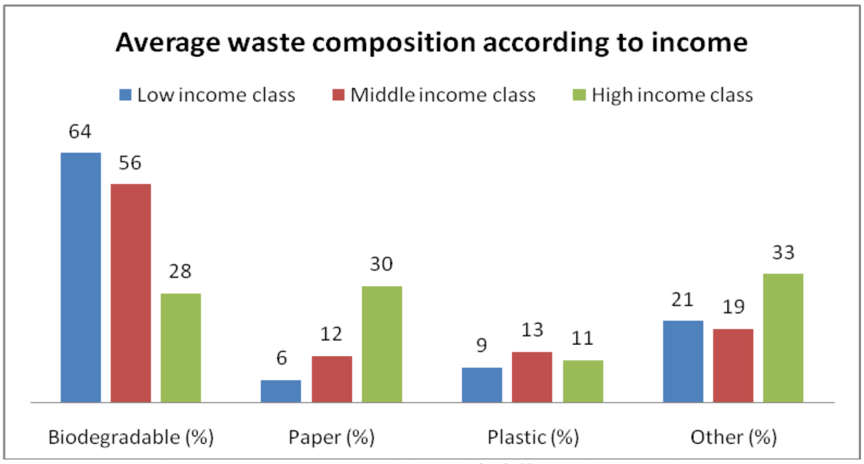

Figure-1. Waste composition with different income class.

Source: Kumar and Samadder (2017).

There is no difference in the types of waste generated in the physical characterization data of MSW in metropolitan cities of India for the last 2 decades, although there is an increase in the quantity of waste produced. Figure 1 show that the urban MSW in India can be classified as 40-50% biodegradables, 15-20% recyclables and 31% of inert wastes with moisture content of 47% and average calorific value of 7.3 MJ/k (Jha et al., 2011; Kumar et al., 2017; Kumar et al., 2020; Leena et al., 2014).

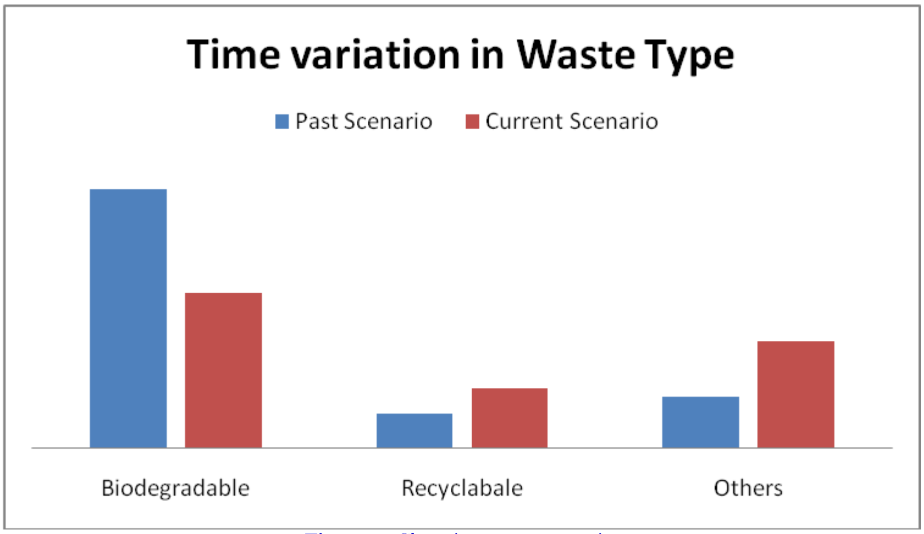

Figure-2. Changing waste scenario.

Source: Abhishek and Mukherjee (2019); Nandan et al. (2017); Paulraj, Bernard, Raju, and Abdulmajid (2019).

The 20th century has led to drastic change in the type of waste produced as shown in Figure 2. Earlier, there were large quantity (70-80%) of biodegradable waste but there is only 45-50% of biodegradable waste and 50% of other waste including plastic, paper, hazardous, biomedical etc (Abhishek & Mukherjee, 2019; Nandan et al., 2017; Paulraj et al., 2019). Higher consumerism, rapid population growth with unplanned urban development, and lifestyle changes have led to increased volumes in solid waste as well as more plastics and certain inorganic materials contents.

The generated waste engagement is not a new cup of tea, but a long pending and ignore field in view of low quantity. The rapid increase in population and industry has grown as shown in data table. The searches for new and new technology are in force, as it has started affecting the human beings. The method like composting, bio methanation and combustion are few oldest methods for waste treatment in India, but limited to organic waste like food / plant material. They basically target organic waste biological decomposition with /without the presence of oxygen, e.g. bio-methanation, combustion. The biggest advantage of such technique is that it does not only reduce nature affecting gas like methane, but also generates – a powerful greenhouse gas. It can simultaneously generate electricity, cooking gas and inert residue which can be used as manure. One of the biggest limitations of these processes is the long and spacious process. Therefore, their rate of treatment fails to target the amount of waste generated, and men has started using the landsite near /outside man colonies for waste treatment and safety issues. Land filling has emerged as one of the cheapest and easiest methods of SWM; burns on low level areas are target areas of dumping solid waste thus leveling the ground for useful purpose. Neither manmade technologies nor nature is capable to treat this huge quantity of waste. The escaped harmful gases and products have started affecting the environment and mankind.

The traditional solid waste management processes, such as composting, bio-methanation and land filling, suffer from the disadvantage of environmental deterioration and space problem, as composting and bio-methanation requires large area for treatment and it takes long period of time. For land disposal of solid waste, India needs 1,240 hectares of extra valuable land every year to include untreated solid waste. As per report published by Ministry of Urban Development, government of India, 2014, Solid waste produced was 133000 MT/day, Total waste collected is 91000 MT/day, waste littered 42000 MT/day, from the collected MSW 26000MT/day is treated and 66000 lakh MT/day landfilled (crude dumping). The waste generated is 133000 MT/day and waste collected, treated , littered and land filled has been shown in Figure 3.

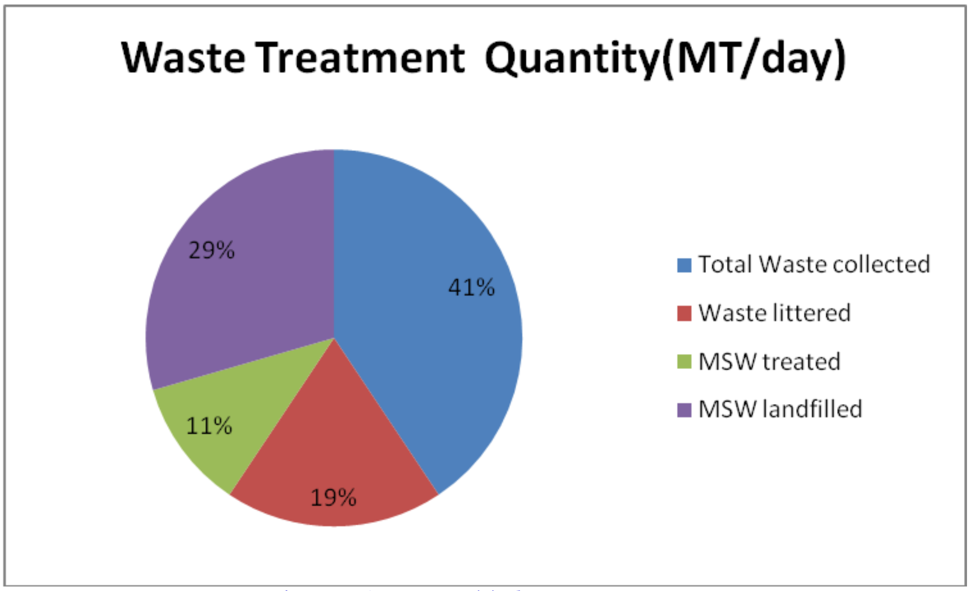

Figure-3. Current municipal waste management.

Source: Central Pollution Control Board (CPCB) (2000) and Central Pollution Control Board (CPCB) (2004) and Satpal (2020).

Figure 4 show a comparisons of various state waste segregation in % .

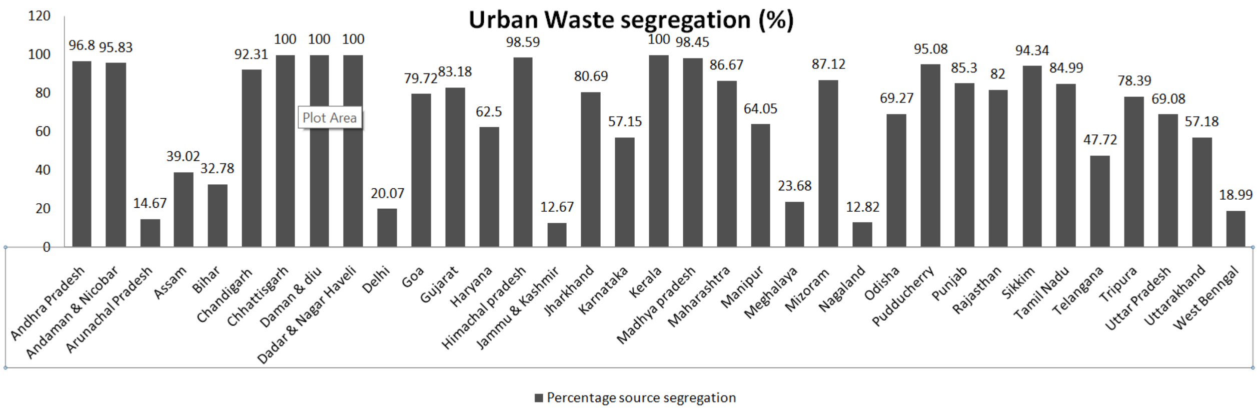

Figure-4. State wise percentage wast segregation.

Date Source: Central Pollution Control Board (CPCB) (2000) and Central Pollution Control Board (CPCB) (2004) and Satpal (2020); Sudha (2008).

The calorific value of Indian municipal waste ranges from 800 Kcal to 1100 Kca and moisture content 40% to 50% .The traditional techniques are time taking processes so heap/ mountain of waste has formed which has affected the aesthetic beauty of the city; and in these processes, foul smell is produced and also contributed to many environmental problems, such as global warming, ozone depletion, human health hazards, ecosystem damages, abiotic resource depletion, etc. (Khandelwal, Dhar, Thalla, & Kumar, 2019). This further leads to a lack of public approval for new waste management sites. The existing landfill sites in mega cities like Delhi, Kolkata and Mumbai have dangerously exceeded their capacity already. Moreover, the traditional waste disposal technique by landfill is considered the most unfavorable route in the waste management hierarchy, as it wastes valuable land and gives rise to Green House Gases (GHG) emissions, primarily methane (Khandelwal et al., 2019).

3. MODERN TECHNOLOGIES FOR MUNICIPAL SOLID WASTE MANAGEMENT (MSWM)

The various studies have been conducted on traditional waste management methods based on cost of the technology, environmental impact assessment, life cycle etc. Top 5 cities in waste processing is shown in Figure 5 (Satpal, 2020). The performance of applied methods is based on their geographical location, and input waste type. All the traditional technologies have shortcomings of waste generation, time required and ash content produced so there is a need of technological advancement in this field which can overcome all these limitations.

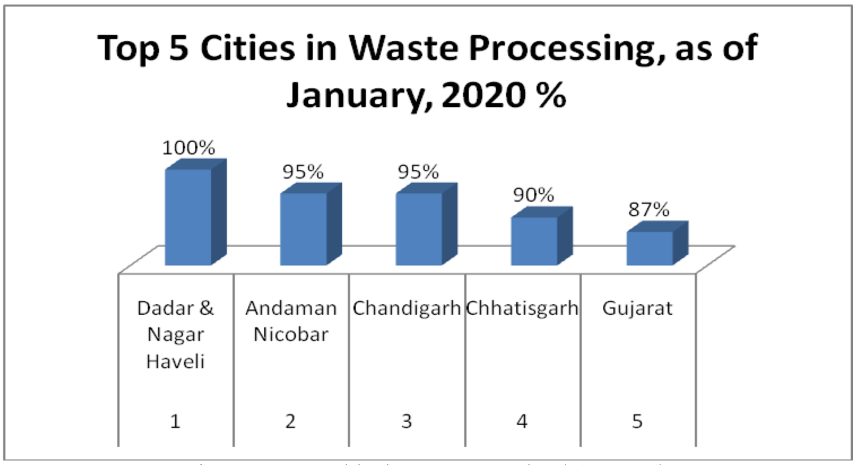

Figure-5. Top 5 cities in waste processing (JAN, 2020).

Source: Central Pollution Control Board (CPCB) (2000) and Satpal (2020).

The various methodologies for waste to energy (WtE) have evolved from combustion, gasification, incineration (Table 2). The different processes of thermo chemical treatment, such as composting, incineration, pyrolysis, etc., are an essential component of the management system of sustainable integrated municipal solid waste (MSW) (Kumar & Samadder, 2017; Otitoju & Seng, 2014; Sudha, 2008). Thermal treatment plants can in fact convert MSW into different energy forms, such as electricity and heat for both utilization in industrial facilities or district heating (Kumar, 2013; World Energy Council Report, 2013; Young, 2010). The advancement in technologies for solid waste management cannot limit generation of waste, the only possible solution can be to help nature to convert waste into natural components. From combustion, gasification, incineration to plasma technology (Abhishek & Mukherjee, 2019; Paulraj et al., 2019) various waste-to-energy (WtE) methodologies have emerged. All WtE itself needs additional material and energy resources and waste as a resource and contributes in absolute terms to a decrease in per capita waste generated (Devi & Satyanarayana, 2001). Table 2 show such WtE plants with energy generation in various Indian cities.

Table-2. Modern technologies for Municipal Solid Waste Management.

	Combustion	Land filling	Incineration	Gasification	Pyrolysis
Aim of the process	Waste to high T flue gases	Maximize waste decomposition,	Waste conversion to high temperature	Waste to high heating value flue gases	Max. thermal decomposition of solid
Flue Gases	CO_2, H_2, CO, H_2O and particulate matter.	CO_2 and CH_4	CO_2 and H_2O	CO, H_2, CO_2, H_2O and CH_4	CO, H_2, CH_4 and other hydrocarbons
Operating condition reaction environment	Oxidant amount larger than required) in presence of air.	Oxidizing at the upper layer and reducing beneath the surface.	Oxidant amount larger in presence of air between 850°C and 1200°C	Lower oxidant in oxygen enriched air, steam Between 550°C and 900° C (in air gasification) and 1000-1600 ° C	Total absence of any oxidant between 500°C and 800°C
Pressure P	Atmospheric	Atmospheric	Generally atmospheric	Generally atmospheric	Slight over-pressure
Pollutants	CO_2, H_2, CO, H_2O and particulate matter.	CO_2, CH_4, SOx, NOx H_2, CO, H_2O & particulate matter.	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
Ash	Large amount of ash is produced.	No ash	Ash – ferrous, non-ferrous metals and inert materials for sustainable utilization.	Vitreous slag that can be utilized as backfilling material	Non- negligible carbon content
Gas cleaning	-	-	Can be made under emission limits	Possible to have clean synthetic gas to meet the standards of chemicals production processes or with high efficiency energy conversion devices	
Waste reduction (w/w)	60%	10-20%	70%	82%	84%
Ash production	Yes	No	Yes	Yes	Yes

Source: Abhishek and Mukherjee (2019); Paulraj et al. (2019); Kumar et al. (2020); Young (2010).

As per 2020 study, almost every state process waster for WtE and Figure 5 show top 5 waste processing cities. Owing to the increasing collection, recycling and reuse of waste are economically viable choices since a large portion of the waste management budget is used to collect and transport waste (Devi & Satyanarayana, 2001;

Khandelwal et al., 2019). Such utilization establishes waste as resources and contributes to the circular economy as a key. 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.

Table-3. Operating WtE plant in India

Operatonal WtE plants in India			
Location	**Developer**	**Capacity (TDP)**	**Electricity Generation (MW)**
Delhi-Okhla	Jindal	1950	16
Delhi- Gazipur	IL&FS	1300	14
Delhi- Bawana	Ramky	2000	24
Hyderabad	Ramky	2400	20
Hyderabad	IL&FS	1000	11
Chennai	Essel	300	2.9
Jabalpur	Essel	600	0.9
Shimla	Elephant Energy	70	1.75

Source: Municipal bodies of different cities/ miscellaneous.

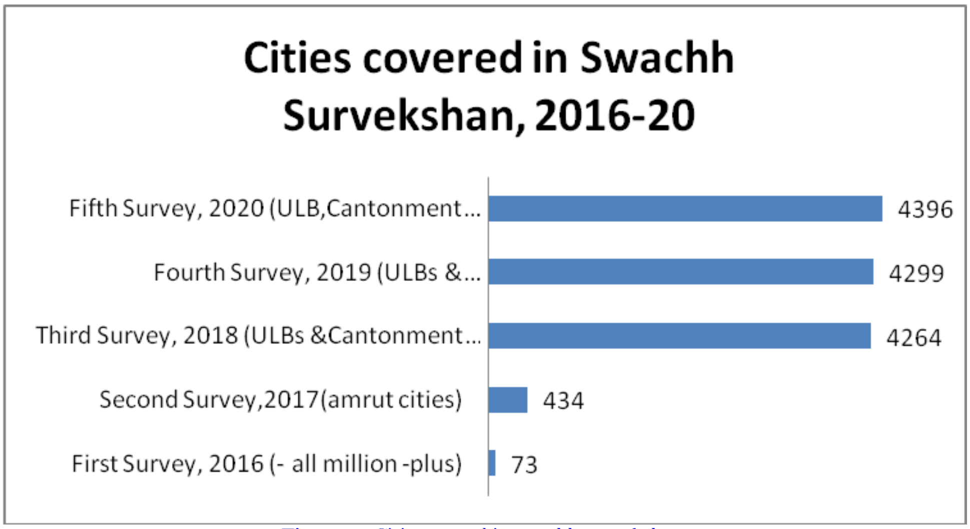

Figure-6. Cities coverd in swachh survekshan.

Source: Kumar (2013); Rada, Istrate, and Ragazzi (2009), Central Pollution Control Board (CPCB) (2000) and Satpal (2020).

4. MSW SOCIAL APPROACH

The various waste planning approaches are based on waste generation quantities, local waste characteristics, local geographical conditions, land accessibility and other relevant criteria. The large volume of waste places special emphasis on community or stakeholder contribution and inter-departmental coordination at the local-authority level to ensure implementation success. The easiest way to reduce waste reaching landfill sites is by involving more stakeholders like NGOs, local people and other organizations. This can be achieved by spreading education and awareness among people about waste as resource, it will help in saving money (Kumar, 2013; Rada et al., 2009).

In this context, various Indian government Initiatives for waste management like Urban Infrastructure Development Scheme for Small & Medium Towns (UIDSSMT), "Recycled Plastics Manufacture and Usage Rules (1999), The Plastics Manufacture and Usage (Amendment) Rules (2003), Central Pollution Control Board (CPCB), Non-biodegradable Garbage (Control) Ordinance, 2006, Municipal Solid Wastes (Management and Handling) Rules, 2000, Swachh Bharat Mission(2014) , Solid Waste Management Rules (2016), are few of them. The government of India also understand the importance of public participation either at source level or management level so public participation has increased from 2016-2020 in Swachh Survekshan (Satpal, 2020) as shown in Figure 6. The sustainable waste management of solid waste without public participation is not possible.

5. PLASMA TECHNOLOGY AS AN ALTERNATIVE FOR INDIAN MSW MANAGEMENT

Plasma is the ionized state of matter and is created through the application of energy sourced from electric discharges of frequencies ranging from Direct Current (DC) to the optical range. It is formed whenever ordinary matter is heated over few thousand degree C, which results in electrically charged gases or fluids. The various developing countries have started using plasma as a most feasible solution to the impending and escalating waste management crisis from household waste to other hazardous wastes such as medical wastes. The plasma treatment is based on their high temperature, intense and non-ionising radiation nature. Thermal plasmas can be used to treat all kinds of waste streams, be it solid such as regular MSWs, liquid such as urine or poisonous gases. Due to the high temperature and high energy density generated by thermal plasma, a large throughput can be accommodated with a small scale reactor. The high flux densities generated by the plasma at the reactor boundaries lead to a rapid attainment of steady state conditions, effectively reducing the start-up and shutdown times. The plasma for MSW is effective in two forms. - Plasma pyrolysis and Plasma gasification (Kumar et al., 2020).

Plasma pyrolysis is the combination of thermal-chemical properties of plasma with the pyrolysis process. It completely decomposes waste material into simple molecules with use of extremely high temperatures of plasma-arc in an oxygen starved environment. This technology is particularly appropriate for treatment of solid waste and can also be employed for destruction of toxic molecules by thermal decomposition. Unlike incinerators, segregation of waste is not required in this process. Another advantage of plasma pyrolysis is the reduction in volume of waste, nearly 95%. The numerous advantages of plasma technology it is evident that in the near future, plasma pyrolysis reactors will be widely accepted for toxic waste treatment. The quantity of toxic emissions (dioxins and furans) is much below the accepted emission standards and does not require segregation of hazardous waste. In addition, the disease causing micro-organisms are completely killed and there is a possibility to recover energy.

In plasma gasification, waste is heated 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. The end result is the production of synthetic gas (syngas), composed pre-dominantly of carbon monoxide and hydrogen, although certain percentage of carbon dioxide and hydrochloric acid are 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 syngas can be piped away and burned to make energy (some of which can be used to fuel the plasma arc equipment), while the "vitrified" (glass-like) rocky solid can be used as aggregate (for road building and other construction). Plasma gasification used for MSW would require no sorting of materials, eliminate the need for landfills, remove long-haul trucking from our roads and be financially viable. Syn gas can also be converted into high-value products such as highly pure hydrogen, fuels, and other valuable chemical compounds.

Plasma is the sole source of heat in both technologies. No combustion takes place and the end result is the production of synthetic gas (syngas).In fact, the syngas may be contaminated with poisonous gases such as dioxins that must somehow be scrubbed out and disposed of, although some contaminated material may also be found in the rocky solid. Such revenue generation can make it financially viable (Kumar et al., 2020). Plasma gasification used for MSW would require no sorting of materials, eliminate the need for landfills, remove long-haul trucking from our roads and be financially viable.

6. PLASMA TECHNOLOGY ASSESSMENT

The plasma technology has many challenges such as high installation cost, moderated community readiness level, requirement of proper waste sorting less popular, limited process understanding. Because of congested and narrow roads, no single collection mode is effective, economical and efficient in India. Because of the heterogeneity of urban waste, the process of selecting the right waste disposal method is complex. Appropriate method of waste disposal can save money and avoids future problems. The cost of plasma technology is relatively high as compared to other technologies but the cost can be balanced with the revenue generation by selling of the products such as electricity generation from syn gas. This technology is solving many problems such as ash disposal. All technologies require land for ultimate disposal of waste but plasma technology is returning all material in atomic form back to the nature/environment.

The rapid increase in population is also affecting the electricity demand of the country. The current available energy supply is much lower than the actual energy demand for consumption in many of the developing countries. At present, major source of energy throughout the world is fossil fuels that meet the demand of approximately 84% of the total electricity generation. With the use of plasma technology, the generated electricity can serve as a potential to overcome the energy demand and load on fossil fuels. 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. 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.

Public readiness can be improved by spreading public awareness about waste to value technology. 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 assessment examine a technology based on requirement, concept and capabilities on a scale of 0 to 9 with 9 being the most mature technology. The plasma gasification technology is rated moderate to high as it partially achieved the first eight levels of TRL.

All technologies require large area for installation, operation and transportation of waste. To overcome this problem, small plants of plasma technology can be in-situ installed. The small plasma technology plant can be installed at a community level or it can be installed in hospitals etc. this will reduce the cost of transportation as well as reduce the traffic on roads from trucks transporting waste. The products can be utilized at the community level itself or it can be sold in market. All technologies have pros and cons related in their application. Considering all the fields and cost to benefit ratio, plasma technology can be said as suitable option for treatment of all type non-biodegradable waste in India.

7. DISCUSSION

The amount of MSW produced in India is rapidly increasing because of population increase and lifestyle change. The utilization of traditional methods for waste treatment isn't sufficient to handle such an outsized quantity of waste. Now Indian government has understood the gravity of the waste management problem, and shifting to science-based solution of waste to energy conversion. The installation of such waste plant at community level can solve our problem. The multiple approaches with the assistance of plasma waste technology through public participation will eliminate the necessity for landfills, remove long-haul trucking from our roads. Government understands the necessity of public involvement and initiated several policies, activities and initiatives like Swatchhta bharat, Zero plastic use in solving MSW problem. Implementation of such policies will help to extend the share recycling of waste and re-using, an economically attractive option. Plasma based WtE is comparatively new technology which has high technical value, high efficiency, high installation cost, but with low awareness level and safety. the top product syngas features a high revenue generation capacity which may make it financially viable and may be a proven solution for all MSW- burning issue in India.

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RESEARCH ARTICLE

PLASMA TECHNOLOGY AS WASTE TO ENERGY: A REVIEW

M. Kumar[1], S. Kumar[2] and S.K. Singh[3]

1. Assistant Professor, Physics, SSNC, University of Delhi, Delhi, India.
2. M.Tech. Scholar, Delhi Technological University, Delhi, INDIA.
3. Professor, Environmental Enginnering, Delhi Technological University, Delhi, INDIA.

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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

Corresponding Author:-M. Kumar
Address:-Assistant Professor, Physics, SSNC, University of Delhi, Delhi, India.

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].

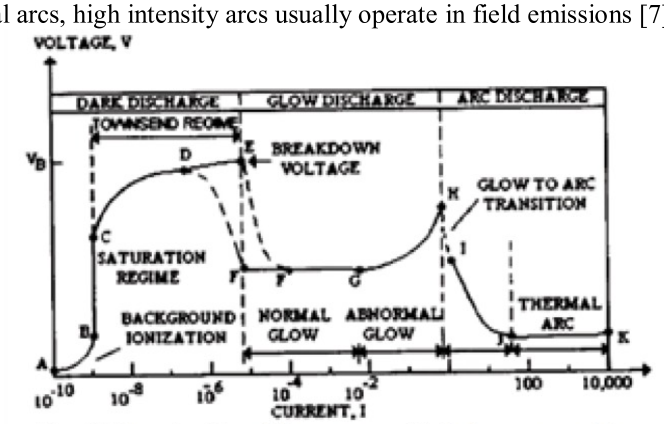


Fig : VI Characterstic of low presuure DC discharge vaccum tube

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.

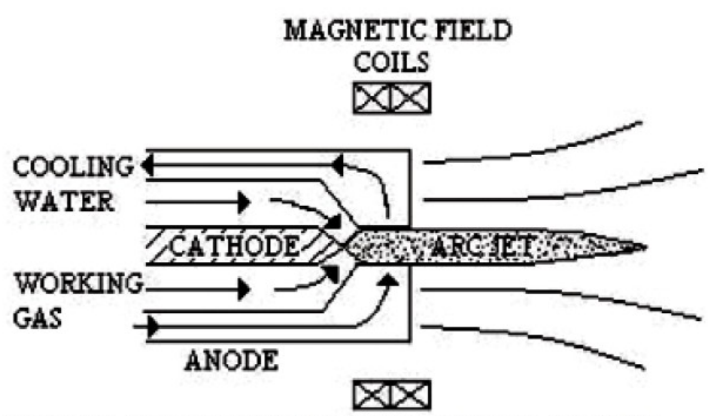
Cold plasma:

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.

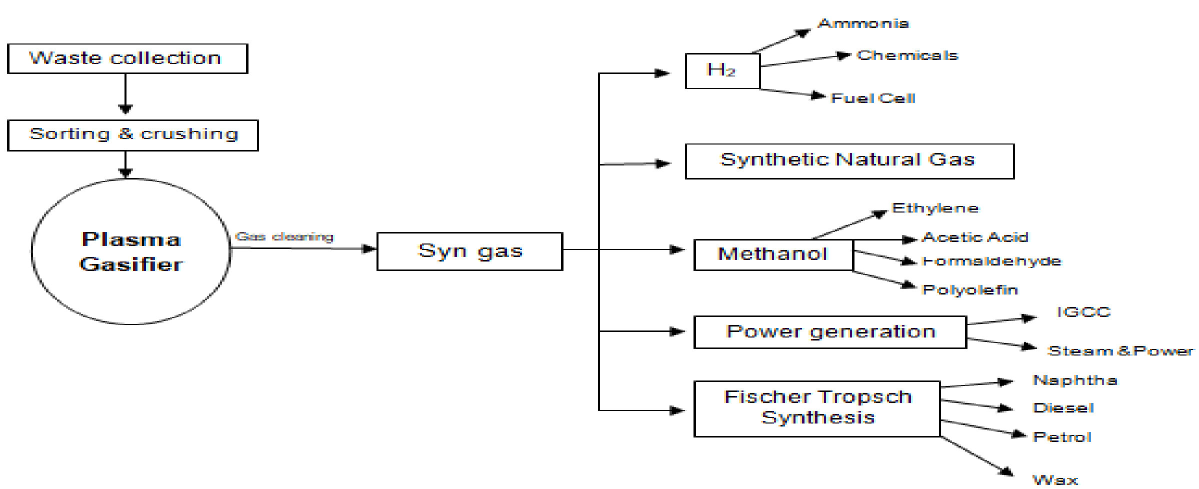


Symmetric, non-transferred, unmagnetized plasma arc jet [7]

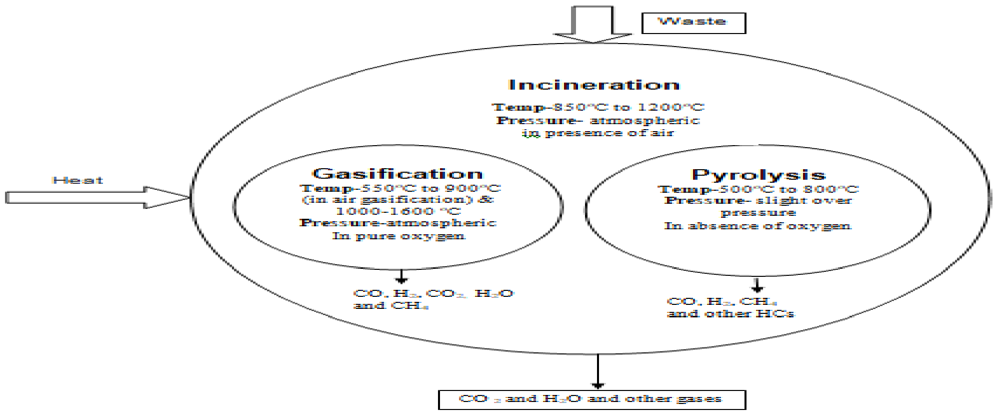
The designs of DC plasma arc generators differ greatly electrode nature,anode separation with respect to the cathode. It is usually a conducting material such as graphite, which also has refractory properties and does not require to be water cooled. It can have a hole through it which will allow the 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.

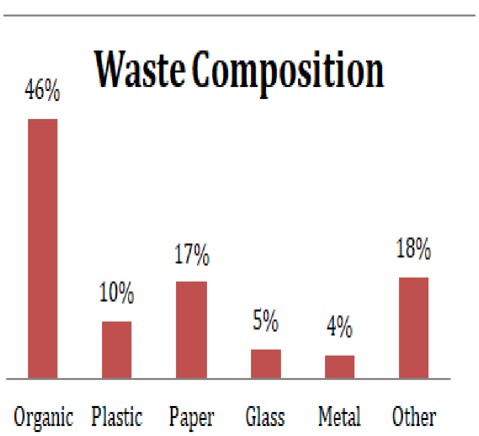


The end result of plasma gasification is the production of synthetic gas (syn gas), composed pre-dominantly of carbon monoxide and hydrogen, although certain percentage of carbon dioxide and hydrochloric acid are also present, along with vitrified slag which contains molten form of all the inorganic 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
Processin g 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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