Central Power Research Institute
Vol. 17(2)/75-80, July-December 2021
ISSN (Print) : 0973-0338
DOI : 10.33686/pwj.v17i2.1065
Power Research

Conversion of Biomedical Wastes to Energy by Plasma Technologies

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Abstract

The Biomedical Wastes (BMW) include variety of materials like plastics, radioactive elements, metals, infectious biomolecules, etc which are hazardous and pose potential health risk to the people when they are directly released to environment. There are many technologies for treating biomedical wastes like incineration, steam sterilisation before landfilling, etc. The plasma gasification is the state of art technology for the safe disposal of BMW and also convert them to energy. The plasma gasification operates at very high temperatures and the conversion percentage is relatively high compared to any other gasification technologies. The concept of plasma gasification for BMW and the other techno economical aspects are discussed in this paper.

Keywords: Biomedical, Biomedical Waste, Plasma Gasification, Microwave, Waste to Energy

1. Introduction

The Biomedical Wastes (BMW) generally contains infectious materials and biomolecules which cannot be released to the environment without pre-treatment. This includes various other materials like leather, food waste, rubber, plastics, textiles, chemicals, medicines, etc. The materials associated with the generation of Biomedical Wastes like packages, unused bandages, etc are also put under the category of BMW. The average calorific value of BMW varies from 12,550 to16,740 kJ/kg[1].

There are several technologies for the treatment of medical wastes. According to the treatment, studies of medical wastes, about 59–60% of them are treated through incineration, 37–20% by steam sterilization (autoclaving), and 4–5% by other treatment methods (landfilling, microwaving, plasma pyrolysis). Healthcare waste incineration has been the major technique used worldwide for disposing materials referred to BMW. Incineration is an engineering process designed to treat healthcare waste by means of thermal decomposition via thermal oxidation at high temperatures between 900 and 1200°C destroying the organic fraction of the waste. However, the incineration process has a potential risk to human health due to formation of furans, dioxins and benzo-pyrene which are toxic.

The autoclaving technology is being used for waste treatment. In this method, steam is used at high temperature and pressure for sterilising the wastes. Alternatively microwave technology with steam is also being used for sterilising wastes by destroying infectious agents and micro-organisms. The types of waste generally treated in microwave systems are the same as those treated in autoclaves. Both the autoclave and microwave systems are used only for sterilisation and the resultant material will be again dumped for landfilling.

Plasma pyrolysis is a modern technology for safe disposal of healthcare waste. It is an environmentally friendly technology that transforms organic waste into useful products, and it is another type of thermal processing of carbonaceous materials. A more promising technology for BMW processing is plasma gasification. In the process of plasma gasification at temperatures up to 3000 K, all materials, even highly resistant cytotoxic and cytostatic drugs, are destroyed forming simple stable substances. It is one of the main advantages of BMW plasma gasification. The plasma gasification guarantees a significant reduction in atmospheric emissions of dioxins, furans and benzo-pyrene (the most toxic products of waste

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processing) to ecological and sanitary-hygienic safety levels, as well as a decrease in the volume of ash and slags, compared to incineration of waste. Due to the strong heat generated by the plasma, it can dispose all types of waste, including municipal solid waste, biomedical waste, and hazardous waste in a safe and reliable manner. The use of electric power for plasma generation is the disadvantage of this process.

2. Concept of Plasma Gasification

Plasma is a fourth state of mater and forms when the gas is ionised by an electromagnetic field. The core temperature of plasma is 4000-12000°C depending on the process and the plasma medium used. The plasma gasification is the process of converting organic matter to syngas at extremely high temperatures. The syngas so formed contains, hydrogen, carbon monoxide and other hydrocarbons. The composition of the syngas depends on the material used, thermodynamics and other process parameters. At this high temperature, the inorganic matters present in the feed material get converted to fused slag. The plasma source for such reactors is either from electric arc or microwave. Due to its high temperature, plasma gasification technology is being used in waste treatment for converting wastes like, refuse derived fuels, biomass, municipal solid wastes, industrial wastes, etc.

3. Process and Methodology of Plasma Gasification

The plasma is generated either using DC or AC discharge which are called arc plasma or using microwave called Microwave Induced Plasma (MIP). In respect of arc plasma, electrodes are used as anode and cathode for generating arc plasma and microwave is used for generating MIP and it is an electrode less process. MIP is the state of art technology. The arc and microwave plasma are given in Figures 1 and 2.

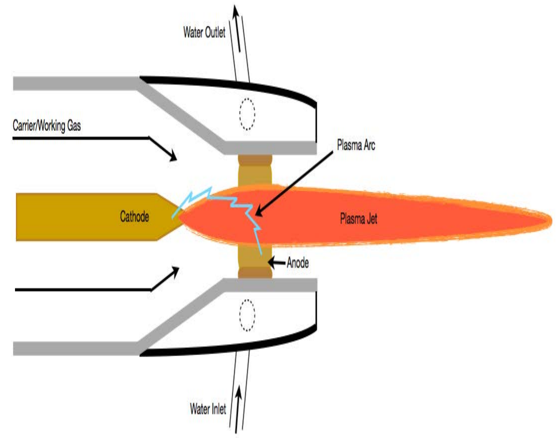

Figure 1. Arc plasma.

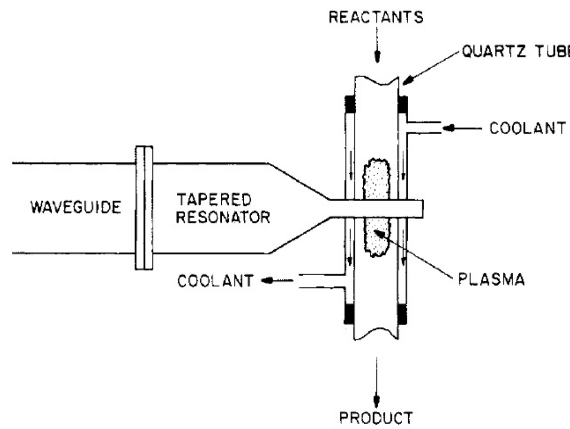

Figure 2. Microwave plasma.

The biomedical wastes are directly subjected to the plasma flame in the absence of oxygen so that the carbonaceous matter forms syngas instantaneously at the high temperature and the inert matter forms vitrified slag. The syngas predominantly contain CO and H_2 with other hydrocarbons can be used as direct fuel for gas/steam turbines or further converted to liquid fuels. The syngas formed from plasma gasification is further purified in the post process for making it suitable for energy generation. The processed syngas can be directly used for generating electricity through gas/steam turbine technologies. Alternatively, the hydrogen content in syngas can be increased by water gas shift reactions and the recovered hydrogen can be used in fuel cells for generating electricity. Syngas can also be converted to liquid fuels by Fischer -Tropsch process and the resultant liquid fuels can be used in gen-sets.

4. Plasma Gasification Plants for Biomedical Wastes

4.1 Components of Plasma Gasification System

Plasma gasification plants need basically three components. i) Pre-processing, ii) Reactor system and

iii) Post processing. The pre-processing includes the receipt and storage of biomedical wastes, processing like shredding and feeding to the reactor system. The reactor system contains the plasma zone, where the BMW is decomposed to form syngas. The reactor includes the plasma generation devices. The post processing includes the slag removal, syngas cleaning and storage. The auxiliaries like cooling system, etc. are similar to any other IGCC plant. The plasma gasification plant can be combined with a gas engine for the generation of electricity. The turnkey manufacturers are available in India for small scale arc plasma gasification plants (up to 5 TPD) that includes arc plasma reactor, pre and post processing systems. The gas cleaning systems and associated auxiliaries for larger capacity is similar to any other large scale gasification plant in India. The microwave based plasma gasification is still in research level in India and no manufacturers for commercial scale plants.

4.2 Electricity Generation from Syngas

The syngas from the gasification of biomedical wastes contains predominantly Carbon monoxide and Hydrogen with smaller percentage of other hydrocarbons and contaminants like hydrogen sulphide, fine solid particles, etc. The syngas to be treated for removing the fine solid particles and other contaminants by cyclones, bag filters and scrubbing methodologies. The processed syngas can be directly used for generating electricity through gas/ steam turbine technologies. Alternatively, the hydrogen content in syngas can be increased by water gas shift reactions and the recovered hydrogen can be used in fuel cells for generating electricity. Syngas can also be converted to liquid fuels by Fischer -Tropsch process and the resultant liquid fuels can be used in gen-sets.

4.3 Power Requirement for Operation of the Plant

It has been reported for a 10 TPD MSW plasma gasification plant located at Cheongsong, Korea[4] that the power consumption is 1.14 MWh/ton (Thermal plasma torch ; 0.817 MWh/ton + utilities 0.322 MWh/ton) with the consumption of 7.37 Nm^3/ton of LPG. However, the cost is non-linear for higher capacity systems and for example it is reported that[4] for a 100 TPD plant the power consumption for thermal plasma torch is 0.447MWh/ton which is almost half to that of the 10 TPD plant. This is due to the reduction in heat loss when the scale goes up.

Table 1. Power requirement for the thermal plasma torch.

Items	10 TPD scale	100 TPD scale
Thermal plasma consumption power	0.817 MWh/ton	0.447 MWh/ton
Heat loss from effluent gases of stack	16%	10%
Heat loss through system walls	14%	7%
Energy recovery	Not used	Used through steam turbine

4.4 Quantum of BMW Required Per Unit Power Generation and Cost of Power Generation

The BMW has the calorific value of about 12,550 to16,740 kJ/kg. Considering the plasma gasification conversion efficiency around 80% and the turbine efficiency about 35%, the quantum of BMW required for generation of unit electricity would be 0.77 kg to 1.02 kg.

The cost is not available for Indian scenario. The construction and operation costs are taken from international references for a 10 TPD (Tons per Day) MSW (Municipal Solid Waste) gasification plant[4]. This is only up to gas storage and the generation system is not included in the cost. The construction cost would be approximately 0.25 million US$/ TPD. However, this varies with the capacity of the plant as given below[4].

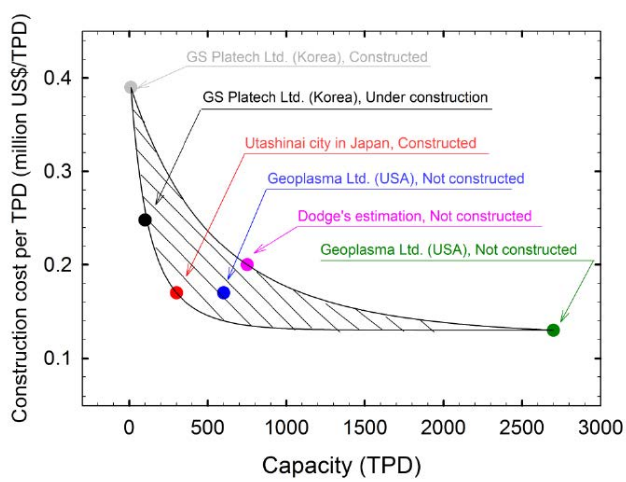

Figure 3. Construction cost for various TPDs.

The operation cost is generally divided into insurance, variable cost and fixed cost. The fixed cost consists of depreciation cost, labor cost and overhead charges. The variable cost includes electricity, chemical, water costs and other maintenance charges. The total cost including both construction and operation for a typical 10 TPD gasification plant is given in Table 2.

Table 2. Construction and operation cost of the existing 10 TPD plant for 3.5 years.

Items			Costs
Construction cost			3.9 million US$
Operation cost per year	Labor costs	12 labors	0.49 million US$/year
	Depreciation cost	Depreciation period = 15 years	0.26 million US$/year
	Variable costs	Maintenance cost Electricity cost Chemical cost Wetted cost Etc	0.24 million US$/year
	Insurance	0.5% of construction cost	0.02 million US$/year
	Total		0.99 million US$/year
	Operation cost per ton of MSW	Total operation cost/330 day x 0.01 day/ton	330 US$/ton (with V.A.T.)
			300 US$/ton (without V.A.T.)

Table 3. Estimated construction and operation cost of 10 TPD plant.

Items				Costs
Construction cost				24.8 million US$
Operation cost per year	Fixed costs	Labor costs	14 labors	0.57 million US$/year
		Overhead charges	Fring benefits Safe maintenance cost Train expense Per diem and travel expenses Etc	0.17 million US$/year
		Depreciation cost	Depreciation period = 15 years	1.65 million US$/year
		Sub total		2.39 million US$/year
	Variable costs		Maintenance cost Electricity cost Chemical cost Wetted cost Etc	0.82 million US$/year
	Insurance		0.5% of construction cost	0.12 million US$/year
	Total			3.34 million US$/year
	Operation cost per ton of MSW		Total operation cost/330 day × 0.01 day/ton	111 US$/ton (with V.A.T.)
				101 US$/ton (without V.A.T.)

Based on the experience of 10 TPD plant the estimated cost for a 100 TPD plant is given below[4]

In respect of biomedical wastes the cost will be little more expensive due to hazardous material handling system.

4.5 Safety Aspects in Plasma Gasification of BMW

General Industrial Safety Guidelines on the handling and treatment of biomedical wastes, machineries like shredders, conveyors, feeders, reactors, high voltage electricity and high temperature protections, etc. to be employed. In respect of Microwave Induced Plasma Generation, the guidelines for microwave radiation related protections to be employed. For handling the hazardous wastes, the Guidelines given by CPCB on Utilisation of medical wastes-February' 2019[2], and Handling of Covid waste- March 2020[3] and other standard existing procedures are applicable.

For increased safety, the medical wastes can be sterilised using autoclave methodologies and the resultant material can be applied to plasma gasification. The autoclave can be coupled with shredders before introducing the waste into plasma gasification system. If the BMW to be directly applied to plasma gasification, care to be taken in respect of handling hazardous materials with minimum human intervention.

4.6 Disposal of Residue After Plasma Gasification of BMW

Most of the biomedical wastes are organic and plastic materials. In plasma gasification at high temperature they will get completely decomposed to form syngas. The inorganic materials are very less in biomedical wastes and they form inert vitrified slag at high temperature. They can be safely disposed for landfilling or for road applications.

5. Availability of Equipment and Consumables in India

Except the plasma gasification methodology the pre-processing, post processing and power generation through gas turbine are similar to a typical IGCC plant. In respect of plasma gasification, the equipment and consumables are available in India for arc plasma gasification and not in the case of microwave plasma gasification. Vendors are available in India for making arc plasma gasification plant up to 5 TPD for medical wastes.

6. Operational Plasma Gasification Plants in Abroad and India

Many plasma gasification plants have been installed at various parts of the world as given in the below[4].

Table 4. Plasma gasification plants in the world

Locations	Population	Materials	Capacity (TPD)	Start date
Europe				
Landskrona, Sweden	27,889	Fly ash	200	1983
Bordeaux, France	1.01 million	Ash from MSW	10	1998
Morcenx, France	4,993	Asbestos	22	2001
Bergen, Norway	213,000	Tannery waste	15	2001
North America				
Anniston, Albama	24,276	Catalytic converters	24	1985
Jonquiere, Canada	54,872	Aluminum dross	50	1991
Honolulu, Hawaii	374,676	Medical waste	1	2001
Richland, Weshington	46,155	Hazardous waste	4	2002
Alpoca, West Virginia	613	Ammunition	10	2003
USA Navy	-	Shipboard waste	7	2004
USA Army	-	Chemical agents	10	2004
Hawwthorne, Nevada	3,311	Munitions	10	2006
Ottawa, Canada	1.1 million	MSW	85	2007
Madison, Pennsylvania	510	Biomass, Const. waste	18	2009
Asia				
Kinura, Japan	40,806	MSW Ash	50	1995
Mihama-Mikata, Japan	28,817	MSW/Sewage sludge	28	2002
Utashinai, Japan	5,221	MSW/ASR	300	2002
Shimonoseki, Japan	1.5 million	MSW Ash	41	2002
Imizu, Japan	94,313	MSW Ash	12	2002
Kakogawa, Japan	268,565	MSW Ash	31	2003
Maizuru, Japan	89,626	MSW Ash	6	2003
Lizuka, Japan	78,201	Industrial waste	10	2004
Taipei, Taiwan	22.2 million	Medical and battery waste	4	2005
Osaka, Japan	2.6 million	PCBs (Poly chlorinated Biphenyl)	4	2006
Cheongsong, Korea	150,000	MSW	10	2008

The MEPL plasma gasification, Pune, India, has been installed by M/s. Westinghouse, USA. This plant has the capacity of handling 72 TPD hazardous waste. The steam power generation unit is attached to the plasma gasification plant.

7. Using BMW with Other Municipal Solid Waste (MSW)

The municipal solid wastes generally have low calorific value compared to biomedical wastes as the percentage of plastic materials is more in biomedical waste. The biomedical waste can be used along with MSW for plasma gasification, however, the handling of hazardous biomedical wastes to be taken care. The cost of operation and investment for the plasma gasification plant for hazardous waste is higher than inert wastes.

8. Advantages and Disadvantages of Plasma Gasification Process

The advantages of plasma technologies for waste treatment are[6]:

- Plasma gasification converts almost all the tough waste into syngas due to elevated temperature
- The slag obtained as by product can be used for the production of value added products
- This technology prevents the dumping of hazardous wastes/biomedical wastes to landfill
- As the organic matter completely converts to syngas and inorganic matter becomes useful slag, there will be zero landfill from waste
- It is a safe means to destroy biomedical wastes
- Plasma gasification avoids the formation of toxic dioxins and furans (common in incinerators) due to elevated temperatures and associated techniques.
- The air emissions are cleaner compared to landfill
- The disadvantages are[6]
- The capital investment and operational costs are high compared to other alternatives like incineration and landfilling
- The net energy production is little or negative in some cases
- Limited plant availability and recurrent maintenance
- Consumes more power for wet feed stocks and reduced syngas production

9. Summary

The biomedical wastes (BMW) include variety of materials like plastics, radioactive elements, metals, infectious biomolecules, etc which are hazardous and pose potential health risk to the people when they are directly released to environment. There are many technologies for treating biomedical wastes like incineration, steam sterilisation before landfilling, etc. The plasma gasification is the state of art technology for the safe disposal of BMW and also convert them to energy. The plasma gasification operates at very high temperatures and the conversion percentage is relatively high compared to any other gasification technologies. The plasma gasification can be enabled through conventional arc plasma or microwave induced plasma. There are many pilot scale and commercial scale plasma plants have been installed around the world and are mostly based on arc plasma technology. The microwave induced plasma has several advantages over arc plasma, however this technology is still in research stage. Albeit the advantages of plasma technology, net energy conversion through this technology is either negative or very low. The improvements through research may increase the percentage of net energy conversion by plasma technologies.

10. Acknowledgment

The authors thank Central Power Research Institute for the supports given and permitting to publish this paper in the conference.

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