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TREATMENT OF ORGANIC WASTE USING PLASMA GASIFICATION

Tamoor Ahmed[*1], **Azhar Hussain**[1]

[1]Department of Mechanical Engineering, University of Engineering & Technology Taxila

A R T I C L E   I N F O

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Author info:
Corresponding Author.
Tamoor Ahmed
tamoorahmed310@gmail.com

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A B S T R A C T

This research investigates the viability of plasma gasification as a method for converting organic waste into energy. Utilizing a plasma arc cutter, the study analyses the efficiency, gas composition, and by-products of the gasification process under controlled conditions. The primary objectives include the quantification of plasma products across different waste compositions and the assessment of energy extraction potential from the generated syngas. The findings reveal that plasma gasification can effectively reduce waste volume while producing valuable syngas, offering a sustainable solution for waste management and renewable energy production. The research addresses the technical, economic, and environmental challenges associated with plasma gasification, providing insights into optimizing the process for small-scale applications. The results underscore the potential of plasma gasification to contribute to a circular economy by transforming waste into energy and other valuable by-products, thus supporting global sustainability goals.

INTRODUCTION

BACKGROUND CHALLENGES AND OPPORTUNITIES:

The increasing generation of waste and decline in accessible and sustainable energy forms are two significant issues that concern contemporary society. Previous handling of waste involved landfill and incineration meaning that environmental impacts included greenhouse gas emissions and cross contamination of soils and water supply. This is because these processes may result in reduction of potential scrap material and may be a cause of the greenhouse effect. At the same time, the global reliance on fossil fuels to meet energy needs is now considered an unsustainable approach, their scarcity and negative effects resulting from the exploration of such non-renewable sources for energy and their utilization through burning. For this reason, plasma gasification has drawn more attention as new generation technology capable of solving two issues associated with waste and energy simultaneously.

By battling high-temperature plasma arcs, organic waste is transformed into syngas, a blend of hydrogen and carbon monoxide plus other gases that are generated from this conversion as well as vitrified solid waste. It also helps to minimize the amount of waste that needs to be disposed of and generates syngas, which can be used to generate power or as a raw material in many chemical manufacturing stages. Although there are many advantages of using plasma gasification, several critical challenges must be met if technology must deliver what is expected of it.

This makes the second generation of biofuels energy negative as much energy must be input for creating a plasma arc and the gasified product requires appreciable quantities of electrical power for maintaining the appropriate temperatures. Gasification can also result in uneven performance because of the variety and variability of waste feeds. Plasma gasification efficiency and stability can be greatly affected by the differences in chemical composition, moisture content, or calorific value of each feedstock as well, so more robust control strategies and adjustable process parameters are needed to further improve this novel thermal power generation system.

Plasma gasification plants are expensive to build in terms of capital investment with costs for plasma torches, reactors, syngas cleaning systems, and other infrastructure. Often this high price component poses a challenge in the transfer of this Third Wave Biotechnology from the laboratory to the marketplace. The plasma reactor suffers a lot from the harsh conditions. Sustainable maintenance strategies for plasma gasification plants are crucial in this sense, given that operational stability and uptime must be at a premium to maintain the long-term health of such facilities. Though plasma gasification emits fewer pollutants than incineration, small quantities of toxic emissions are potentially released during the process. It is important to make the process compliant with environmental regulations and keep emissions of harmful substances under control.

Plasma gasification does have a few big upsides despite all these drawbacks. Use of the power to energy conversion technology, which is an emerging sector not only promises a cleaner zero emissions eco-friendly alternative that provides reliable base-load energy partly from renewable sources but also displaces tens or even hundreds of tons of trash a day in the near future & value addition process over landfilling, offers many benefits; production locks electrification into existing roads and rail infrastructure - decouples mass transport system from oil price shocks. This technology can dispose of different waste kinds, including municipal solid waste, industrial wastes, and hazardous materials making it a universal approach to the disposal of any kind. After that, this syngas can be transformed into synthetic fuels or used directly to produce electricity, making it a part of energy resource diversification and helping us reduce our reliance on fossil fuels.

This is in line with international efforts to move away from fossil fuels for energy production. Plasma gasification is integral to the circular economy philosophy as it makes waste valuable by converting it into a resource. Vitrified slag produced after the process can extend for usage in construction and other purposes, thus, contributing to raw material and resource optimization. Other areas such as plasma technology advanced materials and process engineering can be expanded to enhance the efficiency of plasma gasification systems. Subsequent or enhanced studies in the fusion of plasma gasification with other renewable energy source technologies can prove beneficial in enhancing efficiency and sustainability.

The solution to both problems involves significant application of research and development in technology, economics, and environmental perspectives. Plasma gasification is involved in the clean-up process of waste and handling of these challenges makes plasma processing an imperative tool for enhancing the process of production of energy and trash management to minimize the negative effects of man on the efficient functioning of this planet.

LITERATURE REVIEW

Johnson et al (2019) reported a review on energy recovery from biomass using plasma arc technology. The paper has summarized the methods and technologies used in plasma processing, comparing efficiency and environmental impact. It has been shown that recent progress in plasma technology is associated with enhanced energy consumption and yield products. The paper also elaborates on the ability of plasma technology to handle many varieties of biomass, including leftovers from agriculture and organic waste.

In the current study, Smith, J. et al. (2017) investigated applying pslasma gasification to convert organic waste into syngas and solid residues. The researchers conducted experiments in a laboratory-scale plasma reactor under different operational parameters to enhance the conversion efficiency. It was observed that plasma gasification can efficiently convert organic waste into useful gases like hydrogen and carbon monoxide, with minor by-products formation. The influence of the operating temperature and the impact of gas composition on the effectiveness of the process is discussed, which provides information applicable to scaling up to an industrial level.

Li et al., (2020) discuss the application of plasma arc technology pertaining to waste treatment and energy production. Application of plasma processes for the efficient management of different waste materials and generation of syngas is considered in the paper. It adds an extra analysis insight on the operating parameters like plasma power and gas flow rates, and waste composition impact on the yield and product quality. The paper also delves into the environmental advantages and issues of application of plasma technologies in waste treatment.

Harris, M., et al. (2021) conducted a study on the type and proportions of the different feedstock compositions on the performance of plasma gasification. Different organic materials are utilized, and their impact on gas yield and composition will be discussed. It is a known fact that the carbon, hydrogen and oxygen content in the feedstock has a great impact on the plasma gasification process. The research further draws a comparison between the performances of varying materials under identical plasma conditions.

Environmental and economic analysis of plasma waste conversion technologies have been described by Nguyen, T., et al. (2022). The paper now details cost-effectiveness, the energy demand of the process, and the environmental performances compared with other waste-to-energy technologies. As reported in the authors' works, case studies and simulation lead to a detailed economic analysis based on the capital investment, operational costs, and potential revenue from energy production.

Davis et al., (2019) published results on this project, focusing on optimization of plasma arc gasification applied to organic waste. The work done included a series of experiments in close association with the modeling process for arriving at the best condition for obtaining the maximum yield of gas with least energy consumption. By using a response surface methodology, they pointed out the factors involved in a significant impact on the gasification process's efficiency: feedstock moisture content, plasma power, and residence time. From these, they developed guidelines for enhancing the capabilities using plasma arc technology in the conversion of waste into energy.

Lee and colleagues examined the applicability of thermal plasma to process different types of agricultural waste like plant residues in a study conducted in 2020. They concentrated on determining the extent to which thermal plasma technology can convert these wastes to high energy syngas besides evaluating the environmental effects. According to their findings, thermal plasma processing is very effective in the conversion of agricultural waste and the reduction of pollutants. The study also sought to explore how plasma technology could fit into the existing waste management systems to enhance sustainability.

Zhang and their research group studied the gasification of organic materials employing non-thermal plasma in 2021. Their research targeted at assessing the effectiveness of non-thermal plasma in conversion of various organic substrates into syngas. Specifically, the study focused on the advantages of non-thermal plasma, especially, high gasification rate at relatively low temperature. Specific information was given concerning the nature and amount of by products like tar and hydrocarbons produced in the gasification process.

METHODOLOGY

FEED MATERIAL

The biomass materials used in this work were rice husk, wheat husk, and sawdust. All these materials were collected locally. These wastes were dried in open sunlight and then they were cut into smaller pieces after that they were further grind to obtain a uniform particle size of less than 10mm of waste material. Then they were dried in the furnace at 110oC to remove all the moisture content, the remaining content of solid matter was used for the gasification process. The approximate and ultimate analysis of waste material is given in Table 1.1 and Table 1.2.

Table 1.1 Proximate Analysis of Organic Waste

Biomass type	Rice husk%	Wheat husk%	Saw dust%
Moisture	6.10	8.41	11.99
Volatile matter	63.40	62.39	62.35
Fixed carbon	15.95	23.31	13.36
Ash	14.55	5.59	12.30

Table 1.2 Ultimate Analysis of Organic Waste

Biomass type	Rice husk%	Wheat husk%	Saw dust%
Carbon	43.44	46.37	47.34
Hydrogen	5.35	5.26	5.40
Nitrogen	0.28	1.11	0.31
Oxygen	50.44	46.89	46.16
Sulphur	0.58	0.37	0.78

FACILITIES & PROCEDURES

The test was performed in the experimental setup which consists of a feeding system through which grind and dry waste material having particle size less than 10mm is supplied continuously to the gasification chamber. The alumina pipe having 500mm length and 75mm diameter was used as a reactor. The plasma torch was used as a heating source. Three S-type thermocouples integrated with Arduino are used to monitor and control the temperature in the reaction chamber. At the top of a reaction chamber, the dry waste is fed into the chamber which falls on the plasma. At the end of the reaction chamber, three filter plates are adjusted in the main pipe which permits the volatiles in gaseous forms to pass through them. The ash cannot pass through these filters and is collected in an ash collector which is attached to the main pipe just below the filter plates. The volatiles generated in this process are collected in a gas sample bag after colling it. The volatiles collected at different conditions were tested in a biogas analyzer, which shows the volume fraction of CO, H2, CH4, and CO2. The block diagram of the whole process from the drying of waste material to the formation of product gas and ash is given figure 1.

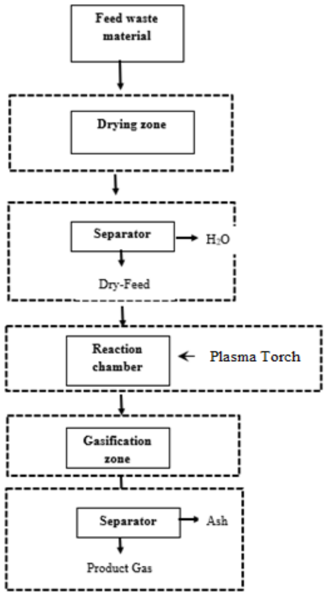

Figure 1 Block Diagram of gasification process

RESULT AND DİSCUSSİON

After performing a series of experiments the volume percentage of each volatile is measured. The simulation is performed on ASPEN PLUS at atmospheric pressure, 2350oC temperature and the equivalence ratio of 0.2. The volume percentage of volatiles in product gas is taken and then compared with experimental data. A good agreement was found between experimental and model data. The maximum relative difference between hydrogen and carbon monoxide is 5.5%, this difference is due to the specific assumptions made in Aspen Plus.

Table 1.3: Experimental and Simulation results for gasification

Parameter	Measurement	H2%	CO%	CH4%	CO2%	LHV(MJ/Nm3)
Temperature 2350℃	Experimental (%)	56.86	38.10	4.22	0.82	15.20
	Model (%)	60.10	35.27	3.86	0.77	16.26
	Difference	4.00	-2.83	-0.36	-0.05	1.06
	Relative difference (%)	5.54%	7.71%	8.91%	6.28%	6.73%
ER = 0.20	Experimental (%)	43.75	31.87	8.12	16.26	15.20
	Model (%)	46.51	29.42	8.87	15.20	16.26
	Difference	2.76	-2.45	0.75	-1.06	1.06
	Relative difference (%)	6.11%	7.99%	8.82%	6.73%	6.73%

Effect of oxygen to biomass ratio on biomass gasification

One of the most crucial process variables is the oxygen-to-biomass ratio and it is computed by dividing the biomass feed rate in dry basis by the mass flow rate of the oxygen injected into the gasifier in the process of gasifying organic waste with pure oxygen. Utilizing pure oxygen as a gasifier will result in a higher CO and H2 composition while lowering the output gas's tar percentage, although the gasifier is expensive. After adequate processing, the mixture represents a zero nitrogen-gasifying agent, increasing the heating value and enabling liquefaction of the generated gas. The O/B ratio (g/g) has a significant impact on how well the gasification system works. It is described as the ratio of the amount of O2 added to biomass added in the gasifier. While varying O/B from 0.1 to 1.0 and keeping other factors constant like temperature which is 2350OC and ER is 0.2 the experiment was performed. When O2 was added, the CO and CO2 concentrations grew and subsequently declined gradually, but the H2 and CH4 contents barely changed. H2 formed when the O2 content was low. produced H2O by using some of the O2. The carbon atoms undergo incomplete combustion and produce CO, resulting in increasing the contents of CO to a maximum of roughly 50%. When O2 levels are too high, H2, CH4, and CO start burning and as a result, the content of CO2 starts rapidly increasing. H2/CO decreased when O/B rose. As a result, adding too much O2 had no positive effect on the syngas' quality. The increase in carbon conversion efficiency with O/B and reaction temperature suggests that more carbon monoxide was released during burning because of O2 and that higher temperatures provided more energy for pyrolysis and gasification. When O/B was 0.5, the LHV of organic waste peaked at 15–16 MJ/Nm3, showing that the syngas had a considerable calorific value.

Table 1.4: Experimental syngas composition at different values of oxygen to biomass ratios

O/B (g/g)	H2 (vol %)	CO (vol %)	CH4 (vol %)	CO2 (vol %)	LHV (MJ/Nm3)
0.0	46.20	42.19	4.96	6.65	14.12
0.2	43.15	40.29	3.50	13.06	14.44
0.4	32.24	49.63	3.20	14.93	15.16
0.6	30.16	47.10	2.80	19.94	16.10
0.8	28.14	43.28	2.40	26.18	13.20
1.0	25.41	39.13	1.80	33.66	12.40

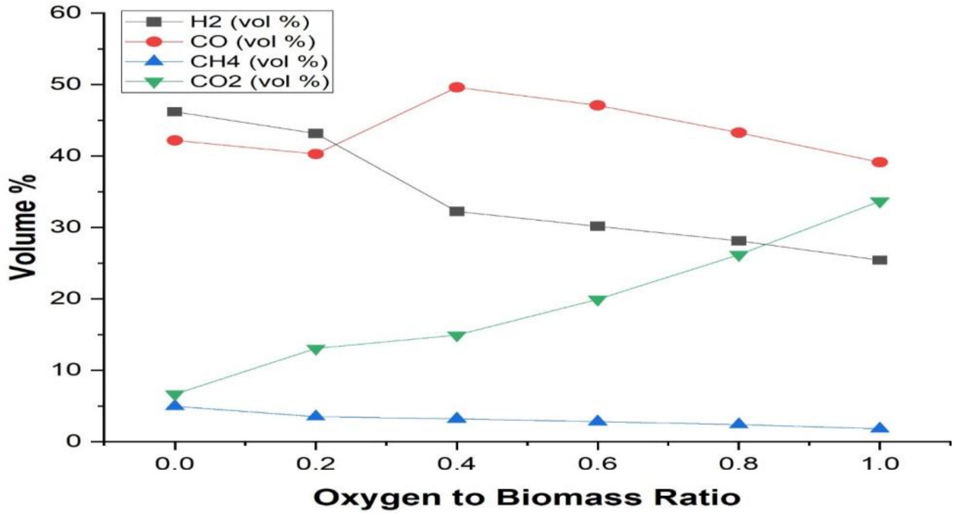

Fig 1.4: Experimental syngas composition vs oxygen to biomass ratio

CONCLUSION & RECOMMENDATIONS

The organic material including rice husk, wheat husk, sawdust, and sugarcane bagasse was selected from the literature review. The moisture content in the organic waste was removed by drying it in the furnace. After that, the dry waste material is supplied to the gasification chamber where plasma is used to burn the waste in a pure oxygen environment. The experiments were performed in different operating conditions by varying the gasifier temperature, equivalence ratio, and oxygen-to-biomass ratio. The useful results for the efficient gasification process at optimum conditions were obtained. It was found that useful components of the product gas are maximum at the temperature of 2350OC, Equivalence ratio of 0.24, and oxygen to biomass ratio of 0.5. The analysis of syngas gas was done in a biogas analyzer, which gives the volume percentages of hydrogen, carbon monoxide, methane, and carbon dioxide in the chemical composition of syngas. The findings demonstrate that when the temperature rises, the hydrogen and carbon monoxide contents in the resultant gas rise quickly. Also, higher equivalency ratios are not recommended for gasification because they cause combustion instead of gasification. Whereas adding too much oxygen produces a large amount of carbon dioxide which decreases the quality of product gases. Using plasma with pure oxygen increases the quality and quantity of volatiles generated from the organic waste. The result obtained can be used to make the gasification process more efficient and to improve the quality of syngas. In the future, it can be used for unsegregated waste at a large scale. The experimental results are compared with simulation results by performing the simulation for the optimum condition of the experiment on Aspen Plus. A good agreement was observed between the experimental data and simulated data. A relative difference between the two results is due to some specific assumptions made in the

Aspen Plus. At this stage, the individual components of the organic waste were considered but in future work, it can be modified for the unsegregated waste. It is found to be an efficient technique to obtain useful energy content from organic waste material.

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