Unlocking the true potential of Biogas: A Sustainable Energy Source

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Abstract: **This research study will focus on biogas, an alternative energy that has special properties and only comes from natural sources like excess food and animal waste. Biogas acts as a possible solution to global issues such as climate change and energy scarcity. The research demonstrated that biogas could have a much smaller carbon footprint than other energy sources, which may prove to be a key to a cleaner planet. These proven benefits may also help farmers and low-income individuals produce energy from inexpensive sources. Furthermore, we achieved significant growth in our understanding of biogas, including how it is produced, its long-term possibilities, and its multiple uses.**

INTRODUCTION

In light of the urgent environmental challenges faced and the increasing energy demands of our society, the need for sustainable and renewable energy sources was urgent and an alternative energy solution that stands out is biogas, offering the dual benefits of environmental improvement and energy security. Biogas derives from the natural degradation of organic matter like animal excreta and kitchen waste , through anaerobic digestion.It is a flexible and readily available energy option that has the potential to significantly change energy .

Understanding Biogas:
Biogas is essentially a combination of methane (CH4) and carbon dioxide (CO2) produced through the microbial degradation of organic matter in an oxygen-free environment - hence the term anaerobic. Biogas forms naturally in landfills, wetlands, and the digestive tracts of animals. Biogas can also be produced when the anaerobic degradation of organic matter is performed at a biogas plant, where microorganisms are able to digest a variety of organic material including agricultural wastes, sewage, food waste, and energy crops into methane gas.

Environmental Benefits:
Biogas provides major environmental benefits compared to conventional fossil fuels. It reduces greenhouse gas emissions by trapping methane which is a very strong greenhouse gas in climate change, and turning it into an energy source. Biogas production also uses organic matter that would create methane emissions if they were left to decompose or untreated, contributing to the greenhouse effect. Therefore, along with the emissions reduction, biogas repurposes organic waste and fits in the economy and also boosts sustainibility.

Energy Security and Sustainability:
Biogas is sustainable and renewable energy source that enhances energy by diversifying the energy portfolio, and reducing reliance on finite fossil fuel resources. Unlike solar or wind power, biogas is not dependent on weather conditions - it can be produced continuously throughout the year, which provides a reliable energy supply. Furthermore, the organic or biological material waste used to produce biogas is plentiful and varied, consisting of agricultural residues and organic waste streams, which provides a sufficient supply to ensure sustainability and resilience against variance in available resources.

REVIEW OF LITERATURE

- Jing Wu, Zohaib Ur Rehman Afridi, Zhi Ping Cao, Zhong Liang Zhang, Souhila Poncin, Huai Zhi Li, Jian E. Zuo, Kai Jun Wang [15] studied biogas production at the micro-scale. This study used a transparent micro-reactor for studying biogas production from granules. The micro-reactor was fed a carbon source in a synthetic feed that contained glucose. The synthetic feed was run at a pH value of 7.2 and the reactor was held at 370C using a heater with a digital temperature controller. Granules were added to an anaerobic reactor fed with wastewater. The granules had different COD concentrations, and the granules produced the maximum biogas in an average time period of 16 hrs. The reactor was designed with porous structures to allow for the internal flow of granules. Granules consisted of a mass transport that is more important than the total reactor volume. The rate of biogas production was dependent upon the size of granules used in the reactor. In this study, they reported on the effect of size of granule on biogas production. The internal structural properties of the granules, including the porosity, pore diameter and channel length, correlated to biogas production. The biogas production rate was proportional to the size of the microbial granule present in the reactor. Among all granule sizes, the large granules exhibited a well-developed internal pore structure that assisted

- Cristina Rodriguez, A. Alaswad, K.Y. Benyounis, and A. G. Olabi focused on producing biogas from grass. The feedstock quality is influenced by the composition of the grass and the time of harvest and the chopping size is a key issue. For anaerobic digestion, the grass must be adequate for the microorganisms to do their job and cause significant surface area prior to feeding the digester and initiate degradation. The more mature the grass the higher the level of cell wall components (lignin, cellulose etc) and the increase level of cell contents (sugars, proteins etc) Pretreatment methods of grass species affects the degradation processes and accelerates biogas production. There are many sources of pretreatments for grass from physical, mechanical, ultrasonic, microwave, thermal, chemical, biological etc. The goal of the pretreatment process is to increase the surface area available when pre treating grass. The production of biogas is related to the grass species and its components. The anaerobic digestion process will be different for grass species and types and crop component content which is low in lignin to increase methane production. These crop components are consider to be more degradable and cell contents. Most pretreatment methods promote biogas production from grass will range from 50% increase. With mechanical pretreatment the biogas production will be around 60% increase.

- Jayesh, D. Vaghmashi, Mr. D. R. Shah, and Mr. D. C. Gosai [19] studied the use of biogas as a transportation fuel for internal combustion (IC) petrol engines, where compressed natural gas (CNG) is typically used as a fuel. The biogas can be compressed and converted into bio CNG. The biogas purification process strips CO2 and HS and lowers water vapor content. In order to use this technology, biogas is converted to bio CNG (a methane-enriched biogas). Bio CNG replaces CNG in these applications. Bio CNG is easily applied to automotive engines with little to no modifications from its original CNG model. **However,** it was found in their study that the brake specific fuel consumption of compressed biogas was higher than compressed natural gas. To further elaborate, emissions of HC and CO decreased with biogas use.

- Bhaskor J. Bora and Ujjwal K. Saha conducted a work on a dual-fuel diesel engine that utilizes both liquid and gaseous (biogas) fuels for operation. At engine startup, liquid fuel from the tank is delivered to begin the operation, after which gaseous fuel is supplied to run the engine on the gaseous fuel. The liquid fuel is referred to as a pilot fuel and the gaseous fuel is referred to as the primary fuel. The common types of pilot fuels used to start the engine include diesel, palm oil biodiesel, Jatropha oil, and soybean oil biodiesel. The utilization of dual-fuel in the diesel engine is achieved by intake of the gas mixture at the inlet manifold, which is a venture gas mixer that facilitates the mixing of biogas with the air to create a pressure drop at the throat. To regulate the supply of liquid fuel, a control lever mechanism is installed. The experiment was conducted with a single-cylinder, variable compression ratio diesel engine. The compression ratio varies from 17 to 18.

- Md. Forhad et al., (2013) studied the production of biogas from various fermentable materials by a small-sized model biogas plant. The biogas plant was designed and built as batch type fixed dome to produce approximately 0.5-1.0 m4 of biogas. Cow dung, poultry waste, and water hyacinth were used as fer-mentable materials. The biogas released from the cow dung, poultry waste, and water hyacinth was evaluated and compared. The biogas production from cow dung, poultry waste, and water hyacinth was found to be 0.034 m3/kg, 0.058 m3/kg, and 0.014 m3/kg, respectively. Poultry waste had the highest production 0.026m on the 8th day; cow dung and water hyacinth had the highest production of biogas at 0.0263 m3 and 0.012 m3, respectively, by the 26th day. The percentage of methane content (the key component) in biogas produced by the different fermentable materials was almost equal across the board

- Tsunatu et al., (2014) studies the kinetics of biogas production from agricultural waste, when the wastes were inoculated with cow dung/poultry droppings at mesophilic temperature, 8% Total Solids and 55 days retention time. The modified first order kinetic model was used to determine the kinetics of the biodegradation of the digestion process. A plot of 1/(In(dyt/dt)) against 1/t, derived from the model gives the actual rates of substrate biodegradability and removal of the biodegradable fractions from the substrate. The results show that maize cobs (MC) has the highest short term biodegradability index of 1.5827, and the substrate from biodigester D (SB) has the lowest rate of the biodegradable fractions (k) of - 0.302 of all the substrates. The biodigester C (Rice Straw) produced the highest yield of biogas with a cumulative volume of 692.9ml and an R2 value of 0.8424, while the D biodigester (Sugarcane Bagasse) produced the lowest volume of 185.9ml and an R2 value of 0.6479.

- Sangeetha et al. (2014) examined the feasibility of biogas produced from poultry waste and from a mixture of poultry and fish waste. Fish wastes have significant potential as a source of high valued organic carbon for methane production and generally have high ammonia nitrogen content. In our experiment we found greater biogas yield from the poultry waste than from poultry droppings. We co-digested poultry waste and cow dung at a ratio of 3:2, and we co-digested poultry waste with a mixture of cow dung and fish waste at a ratio of 2:2:1. In both situations, we measured biogas production using a water displacement method. Our digesters were approximately 20 litres in size, and we fed the waste into the digesters in a series of different ratios. Biogas produced by anaerobic digestion was captured in water bottles with Braine solution of sodium hydroxide, and the rise in liquid level in the bottles indicated the volume of biogas produced by anaerobic digestion.

METHODOLOGY

A. Research Design:
Explain the overall structure of the research.

B. Site Selection Criteria:
- Detailed criteria for selecting sites was based on topics such as production and uses of biogas for the topic Biogas, turning waste into energy a sustainable energy solution.
study.
- Justify the selection based on factors like the availability of wastes in area.

C. Demands :
-An introduction shows the necessity of biogas as a source of renewable energy is presented.
-The increasing demand for biogas in the energy section showed to be increased in the coming years. Biogas production process and the sources to get the biogas are presented

D. Technology Implementation:
- Describe the specific anaerobic digestion in large tanks.
- Discuss the integration process with the existing biogas system

E. Data Collection:
- Outline the methods(secondary data) employed to collect data on energy
production, environmental impact, efficiency and effectiveness
- use of sensors, surveys etc .

OBJECTIVES

The evaluation of biogas potential as renewable energy depends on environmental considerations and economic value alongside social advantages.
This investigation discusses the conversion efficiency of organic waste by anaerobic digestion processes for biogas production while evaluating its importance for sustainable waste management systems.

An assessment of biogas's ability to decrease greenhouse gas emissions plus its part in climate change mitigation.

The feasibility investigation focuses on determining how biogas can operate as distributed energy systems that strengthen decentralised energy success.

The research studies current biogas production technology improvements focusing on pre-treatment techniques together with microbial enhancement technologies for enhanced efficiency.

Biogas serves as a prospective substitute for conventional fossil fuels through its bio-CNG expressions in transportation applications.

The study evaluates economic feasibility and policy structures which promote the spread of biogas production infrastructure as well as its large-scale deployment domestically and internationally.

Researchers must investigate both barriers and resolution strategies which affect biogas use within agriculture and waste disposal along with industrial sectors.

A study will assess the production performance of biogas through examinations of agricultural waste together with municipal waste as well as livestock manure.

The author presents plans to combine biogas systems with current energy networks while upholding sustainability principles and operational sustainability.

FINDINGS OF STUDY

Currently, the focus is to work on small-scale installations for testing in a controlled environment the potential for different materials and the possibility to develop new bioreactors for further use in anaerobic fermentation processes.

The present chapter will highlight a part of the research conducted so far, covering three main parts: Figure 1.The figure below presents the test rig developed for firing tests

• Testing in firing processes of biogas and biogas – like mixtures – for this study, the used biogas recipe contained methane and carbon dioxide in known volume participation, initial tests were performed without catalysts and further determinations were carried on using different types of laboratories determined catalysts to determine their potential influence during the combustion process;

• Laboratory analysis on biomass substrates for determining their physical and chemical potential for different applications – the analysis for chosen biomass was performed by the European Standards for solid biofuels (EN ISO 18134 – Solid biofuels – Determination of moisture content – Oven dry method (3), EN ISO 18122 – Solid biofuels – Determination of ash content; EN 14918 – Solid biofuels –Determination of calorific value; EN ISO 16948 – Solid biofuels – Determination of total content of carbon, hydrogen and nitrogen; EN ISO 16994 – Solid biofuels – Determination of total content of sulfur and chlorine; EN ISO 18123 – Solid biofuels – Determination of the content of volatile matter; CEN/TS 15370 – Determination of ash melting behaviour);

• Laboratory studies for biogas production and system development in terms of parameter monitoring and initial inputs for new different materials used for anaerobic digestion processes – the test rigs for laboratory determinations were developed in house and the main testing conditions involved using a known temperature regime (mesophilic or thermophilic), the existence or absence for materials homogenisation, and continuous measuring of pH, and volume participation of methane, carbon dioxide and hydrogen sulphide in the produced biogas.

As it can be observed above, from left to right there are the following components: biogas pipe, connected with the system for pressure control and measuring, the burner (in yellow) and the entrance to the firing chamber, where the tests were carried out. At the end of the chamber, there were measured the flue gas and the temperatures were determined at specific points on the outside wall of the testing chamber. The next images will present some results for the measurements of the flue gas. The equipment used in this regard was TESTO 350XL and DELTA 1600 S IV gas analysers.

FIGURE 2. presents the time variation of NO and NOx during the combustion process of biogas containing around 75% methane and 24% carbon dioxide. The produced biogas was without a filtering system. From the presented graphic, it can be determined that the nitrogen oxides concentration is very low (ppm values), at around 40–43 ppm, which represents very good results in this context.

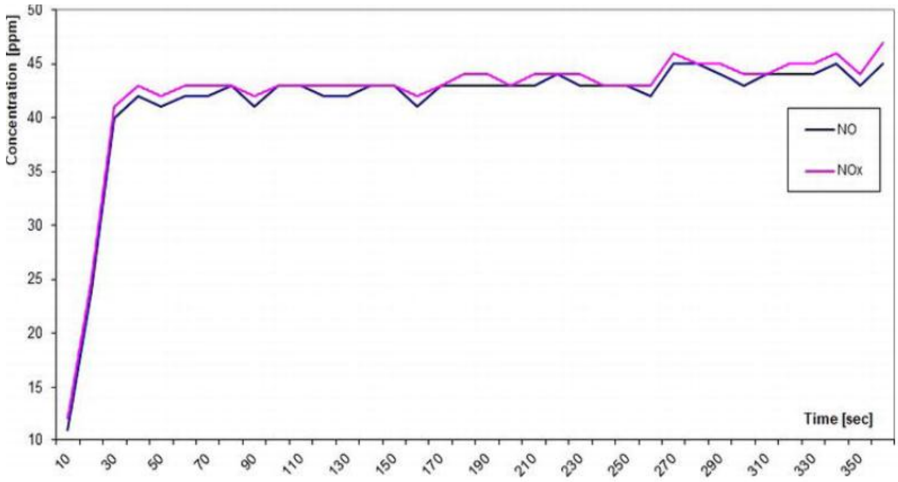
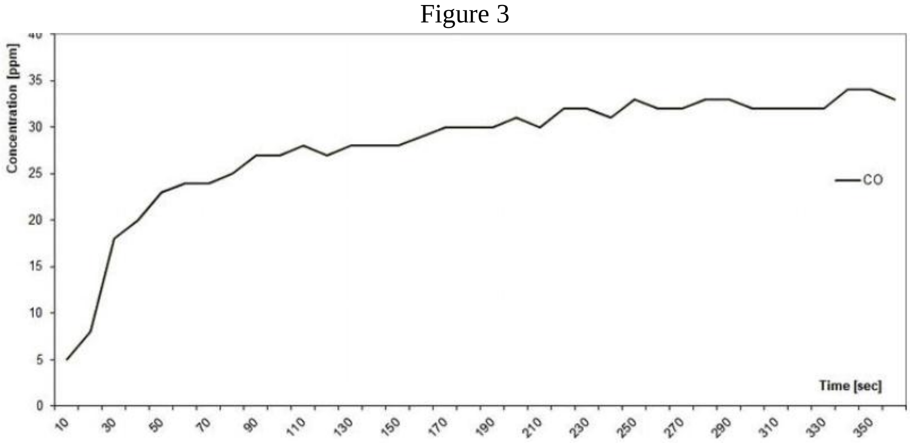


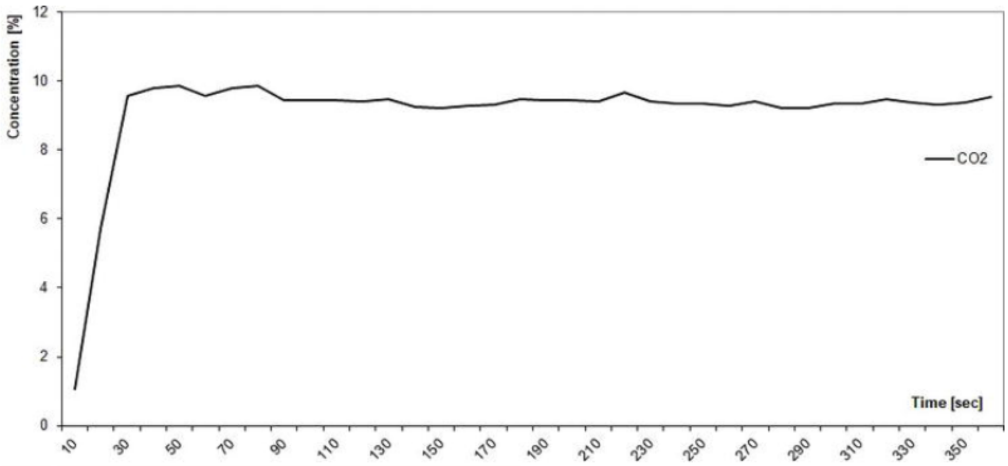
Figure 3



CO concentration evolution in time.

Carbon monoxide is one of the most dangerous flue gasses in high quantities and it needs relatively high temperatures and safe firing conditions to be present in low concentrations. The maximum values for CO concentration during the process are also very low, at around 35 ppm, a very good indicator for a relatively complete firing process. The obtained values used by parallel measurement with all the other existent flue gas, indicated the low volume presence of CO which is a positive argument for a very safe firing process.

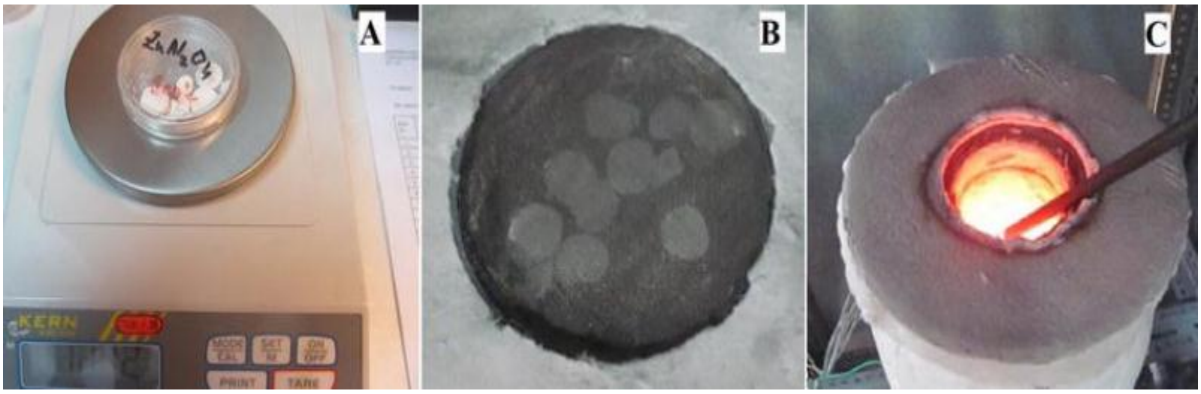
Figure 4



CO_2 concentration evolution in time.

The tests were carried out in the presence and absence of catalysts to observe their influence over the firing parameters and also the flue gas was analyzed with the help of a Horiba gas analyzer coupled with a special developed system used for data collection and registration, containing temperature and pressure sensors, and data control and storage equipment

Figure 5



Preparation of $ZnAl_2O_4$ catalysts: A – Weighting; B – Insertion in the metal matrix; C – Initial testing with and without catalysts.

The used catalysts were $ZnAl_2O_4$, $CoAl_2O_4$ and$ZnCr_2O_4$. The obtained pellets were inserted in a metal matrix for protection purposes and the firing chamber was prepared for preliminary tests.

Before recorded measurements, there were made some preliminary trials to calibrate all the necessary equipment and sensors on the used firing chamber.

Figure 6.

Temperature values inside the combustion chamber, without catalyst presence.

Excess air				[-]	2.0				
Burner power				kW	1.5				
Fuel ratio CH_4:CO_2				[-]	80.4:19.6				
Fuel lower heating value				[kJ/m³]	28847.52				
Fuel consumption				[m³/h]	0.1872				
Air consumption				[kg/h]	3.7041				
Burner pebble bed diameter				[mm]	13				
Burner pebble bed height				[mm]	253				
Burner pebble bed porosity				[-]	44.94				
Flame arrestor bed diameter				[mm]	6				
Flame arrestor bed height				[mm]	107.5				
Temperature distribution within the porous burner – gaseous phase									
-0.1	0	0.11	0.22	0.33	0.44	0.55	0.66	0.77	0.99
t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8	t_9	t_{11}
80.5	354	1022.3	1123.8	1093.5	1072.5	1036.5	980.4	951.9	843.2
Temperature distribution within the porous burner – solid phase									
0		0.44		0.66		0.88			
t_{s1}		t_{s3}		t_{s4}		t_{s5}			
784.3		1058.2		1012.6		943.0			
Flue gas analysis at the exit of the burner									
O_2 [%]		CO_2 [%]		NOx [ppm]		CO [ppm]			
11.10		6.63		1		28			

SUGGESTIONS

Agriculture: Biogas-powered machinery and equipment for on-farm energy generation and decentralized power supply, reducing reliance on fossil fuels and grid electricity.

Waste Management: Implementing decentralized biogas plants in urban and peri-urban areas for the treatment of organic waste streams, including municipal solid waste, sewage sludge, and food waste.

Energy Generation: Technical and economic viability of biogas as a distributed energy resource for electricity generation, heat production, and cogeneration applications in residential, commercial, and industrial sectors

Rural Development: Socio-economic impacts of biogas deployment on rural communities, including job creation, income generation, and improved access to clean energy services and sanitation facilities.

Transportation: Use of biogas as a sustainable alternative fuel for transportation, particularly in the form of compressed natural gas (CNG) or liquefied biogas (LBG), for buses, trucks, and fleets.

CONCLUSION

This paper explores various methods of biogas production and emphasises the importance of reducing reliance on crude oil and petroleum products such as petrol and diesel. Biogas production is a feasible solution, particularly through agriculture biogas plants commonly found in rural areas, which can satisfy daily energy needs for heating, cooking, and more.

Utilising grass for biogas production requires a pre-treatment method to significantly enhance the production rate by up to 50%.

Many private dairies encounter challenges with the disposal or utilisation of cattle dung in urban areas. Biogas technology offers a solution to this issue.

Biogas finds application in diverse areas such as electricity generation and powering internal combustion engines.

India, facing a substantial energy demand, expends significant funds on importing petroleum and natural gas. Embracing biogas and biomass can alleviate this dependency and fulfill the nation's energy requirements more sustainably.

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