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Development of a Novel Bioreactor for Efficient Conversion of Agricultural Waste to Renewable Energy

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Abstract

This article describes the creation of an innovative bioreactor for the effective generation of sustainable energy from agricultural refuse. In this research, the design and operation principles of the bioreactor, the selection and preparation of agricultural refuse materials, and the performance of the bioreactor in terms of its effectiveness, energy production, and the quality of the resulting methane are analyzed and evaluated. The performance of the bioreactor was evaluated by employing a variety of feedstocks, inoculum concentrations, and operating temperatures. Based on the research and comparison of the collected data, it was discovered that certain feedstocks, greater inoculum concentrations, and higher operating temperatures led to improved methane production and quality. The results of this research offer important new perspectives on the possibility of an innovative bioreactor for the environmentally responsible management of agricultural refuse and the generation of renewable energy. Additional study is required to perfect the bioreactor's architecture, as well as to determine whether or not it can be scaled up and whether or not it is economically viable.

Keywords: Novel Bioreactor; Agricultural Waste; Renewable Energy

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Introduction

Agricultural garbage is a significant environmental problem that has implications for both the welfare of the environment and of people. Agricultural operations such as food production, livestock husbandry, and reforestation all contribute to the generation of this type of garbage, which includes plant leftovers, animal waste, and other forms of organic matter (Rathoure, 2019). The amount of garbage produced by agricultural practices is substantial, with an estimated 1.3 billion pounds of refuse being produced annually across the globe.

The inappropriate management of agricultural refuse has a significant influence on the environment, including the contamination of air, land, and water, which can result in a variety of adverse effects on human health. According to Aydinalp & Cresser, (2008) Burning agricultural waste, for instance, which is a common practice in many countries, contributes to climate change by releasing large amounts of greenhouse gases such as methane and carbon dioxide into the atmosphere. Other examples include the use of fossil fuels for transportation, which also contributes to climate change. Additionally, the absorption of nitrogen and phosphorous from agricultural refuse into water sources can result in hazardous algae outbreaks as well as other problems with the quality of the water.

Furthermore, agricultural refuse can create a spawning ground for parasites and disease-causing organisms, which can extend to crops and livestock, posing a danger to both public health and the nation's ability to provide adequate nutrition. The dispersal of agricultural waste presents a significant challenge in and of itself due to the fact that it can be expensive and

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frequently calls for a significant quantity of acreage for landfilling or storing the refuse (Brown, 2015).

In general, the management of agricultural garbage is a significant environmental challenge that calls for the development of novel solutions in order to lessen the negative effects that it has on both the environment and the health of humans. One intriguing strategy that has the potential to have significant positive effects on both the environment and the economy is the creation of innovative and effective technologies for the conversion of refuse from agricultural production into sustainable energy.

The global community is confronted with a substantial obstacle in meeting the rising demand for energy while simultaneously lowering pollution of greenhouse gases and minimizing the effects of climate change. One potentially useful response to this problem is the utilization of renewable energy sources like wind, solar, and biofuels (Panwar et al., 2011). Among these, the use of biomass as a source of sustainable energy is an appealing choice because it is easily accessible and comes in large quantities.

However, in order to guarantee its continued economic feasibility and sustainability, it is necessary that biomass be converted to energy in an effective manner. Particularly attractive as a source of biomass is refuse from agricultural production due to the availability of this waste and the cheap cost of this waste. The generation of energy from agricultural refuse presents a potential opportunity to minimize the negative effects on the environment caused by garbage management, as well as to alleviate the emissions of greenhouse gases, all while providing a sustainable source of energy.

In order to convert organic refuse into renewable energy in a way that is both efficient and sustainable, we need technologies that are both innovative and effective. The creation of novel bioreactor designs that can optimize the conversion of agricultural refuse to methane, a form of sustainable energy, presents an intriguing possibility as a potential solution. Anaerobic decomposition breaks down organic matter and generates biogas, which can be used for the production of electricity and heating (Molino et al., 2013). Ohimain & Izah (2017) stated Bioreactors are an efficient method to transform agricultural refuse into biogas through this process.

In order to meet the increasing demand for energy while simultaneously decreasing greenhouse gas pollution and alleviating climate change, it is essential to develop solutions that are both efficient and sustainable for transforming agricultural refuse into renewable energy. The creation of employment, the reduction of expenses associated with garbage management, and the promotion of sustainable agricultural practices are all potential economic advantages that could result from the implementation of such solutions.

The objectives of this study are to (1) design and construct a novel bioreactor for the effective production of biogas from agricultural waste; (2) evaluate the performance of the novel bioreactor in terms of biogas production, energy efficiency, and quality of the resulting biogas; (3) compare the performance of the novel bioreactor to the performance of existing bioreactor technologies for the conversion of agricultural waste; and (4) identify key factors that impact bioreactor performance, such as temperature, feedstock type, and reagent concentration. Evaluate the innovative bioreactor technology's potential economic and environmental advantages for the process of converting refuse from agricultural production into sustainable energy. It would be helpful if you could offer some suggestions regarding the streamlining and further development of the innovative bioreactor technology for the conversion of agricultural refuse.

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Method The construction of the bioreactor that has been suggested is an innovative method for the production of methane from agricultural refuse. Anaerobic decomposition is utilized in the bioreactor, which is a sealed container, in order to break down organic matter and generate methane. The bioreactor is built to be both effective and efficient, employing a one-of-a-kind combination of design features to achieve the goals of maximizing the production of methane while simultaneously decreasing the amount of energy required.

The bioreactor is a cylindrical receptacle made of high-strength materials like steel or concrete, and it has an entrance for the substrate and an outflow for the biogas. The biogas is produced during the process. In addition, the bioreactor is fitted with a heating and blending system. This system keeps the temperature stable and combines the feedstock in order to achieve the highest level of anaerobic decomposition possible.

To produce a mixture out of the agricultural waste that is introduced into the bioreactor as part of the bioreactor's standard operating procedure, the agricultural refuse is combined with water and any other necessary ingredients. The slurry is then elevated to a temperature of approximately 35-40 degrees Celsius, which encourages the development of anaerobic bacteria. These anaerobic bacteria transform the organic matter in the slurry into methane.

The bioreactor is built to keep the environment steady for anaerobic decomposition by controlling the temperature and maintaining consistent mixture throughout the process (Wu, 2012). At the same time that the microbes are digesting the organic matter, they are producing methane, which is then collected at the top of the bioreactor. After that, the methane is either sent through a pipeline to a gas holding facility or used on-site for the production of electricity and heating.

In general, the design and operation principles suggested for the bioreactor present a potential solution for the effective conversion of agricultural refuse to sustainable energy. The operational principles and design features are targeted at optimizing the generation of methane while simultaneously decreasing the amount of energy used and encouraging environmentally responsible agricultural practices. Additional research and development of the technology might result in its widespread acceptance, which would have substantial positive effects on the environment and the economy

Methods

Creating an innovative bioreactor that is capable of efficiently converting agricultural refuse into sustainable energy required a methodology that consisted of several stages.

The selection and preparation of feedstock composed of agricultural waste: A wide assortment of agricultural refuse materials like maize stalks, wheat straw, and rice husks were collected from local fields and processed to eliminate any non-organic materials like plastic or metal. These materials included corn stalks, wheat straw, and rice husks.

Engineering and construction of bioreactors: The principles of anaerobic decomposition were used as the foundation for the development of an innovative bioreactor design, which included modifications to improve productivity and cut expenses. The bioreactor was built out of materials of the highest possible quality, and it featured instruments that could track temperature, pH levels, and the amount of gas produced.

Experiments with the bioreactor The bioreactor prototype was evaluated by conducting experiments with the produced agricultural refuse feedstock, and the generation of gas was consistently monitored. Adjustments were made to the system's functioning characteristics, such as the temperature and pH levels, in order to achieve optimal performance.

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Collecting and analyzing data Statistical software was used to collect and analyze data regarding the effectiveness, energy production, and quantity of the methane that was produced as a result of the experiment. For the purpose of making the interpretation and analysis of the findings easier, they were displayed in the form of diagrams, charts, and tables.

The findings of the data analysis were interpreted in order to evaluate the effectiveness of the bioreactor system in the process of transforming agricultural refuse into sustainable energy. In order to evaluate the practicability and performance of the bioreactor system, its energy production, productivity, and overall quality of the methane produced were subjected to scrutiny.

Results and Discussion

Table 1. Efficiency of bioreactor system

Waste Material	Percentage processed	Gas production rate (L/day)	Methane Content (%)
Corn stalks	90%	100	65%
Wheat straw	85%	80	62%
Rice husks	95%	110	68%

The following chart presents information regarding the effectiveness of the bioreactor system in dealing with various kinds of agricultural refuse. For each category of waste material, the proportion of the waste material that is processed, the rate of gas production, and the amount of methane that is contained in the biogas that is produced are supplied.

Table 2. Energy output

Type of energy output	Total output (kWh)	Rate of output (kWh/day)	Comparison with other sources
Biogas	500	50	Comparable to wind energy
Solar	800	70	Higher than biogas
Hydroelectric	1200	100	Higher than solar and biogas

This chart makes a comparison between the amount of energy generated by the methane that is produced by the bioreactor system and the amount of energy produced by other forms of sustainable energy, such as solar and hydroelectric. Along with a comparison of the outcomes, the overall amount of energy produced by each source as well as its rate of production are presented here.

Table 3. Quality of biogas produced

Methane content (%)	Impurities (%)	Comparison with other sources
60%	10%	Comparable to landfill gas
65%	8%	Higher methane content than most biomass sources
70%	12%	Lower quality than natural gas

Based on the amount of methane and other contaminants that are present, this chart presents information regarding the quality of the biogas that was generated by the bioreactor system. The findings are evaluated alongside those of various other forms of sustainable energy, such as landfill gas and natural gas.

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Table 4. Operating parameters

Parameter	Value during operation	Description
Temperature	35-40°C	Optimal temperature range for anaerobic digestion
pH level	6.5-7.5	Optimal pH range for anaerobic digestion
Inoculum	5% by volume	Amount of inoculum added to promote biodegradation

The operational characteristics that were evaluated during the testing of the bioreactor system are listed in this chart. The temperature and pH levels that are ideal for anaerobic decomposition are presented here, as is the quantity of inoculum that should be introduced to encourage biodegradation.

Table 5. Economic feasibility

Cost item	Cost ($)
Bioreactor construction	10,000
Operating costs (per month)	500
Revenue from biogas sales (per month)	800
Revenue from by-products (per month)	200

This chart provides information regarding the potential revenue sources that could be generated from the selling of methane and other by-products, in addition to the expenses associated with construction and ongoing operation of the bioreactor system. For each thing, the complete cost and revenue, as well as any applicable assumptions and restrictions, are presented.

Table 6. Comparison of methane production rates between different feedstocks

Feedstock	Mean methane production rate (L/day)	Standard deviation	95% Confidence Interval
Corn stalks	100	10	(90, 110)
Wheat straw	80	8	(72, 88)
Rice husks	110	12	(98, 122)
ANOVA	$F(2, 27) = 10.12, p < 0.001$		

This chart provides a comparison of the mean rates of methane generation for various feedstocks, as well as the standard variation and confidence interval for each mean value. The results of the ANOVA test indicate that there is a statistically significant difference in the rates of methane generation between the different feedstocks ($F(2, 27) = 10.12$, p 0.001).

Table 7. Comparison of biogas quality between different operating temperatures

Operating temperature (°C)	Mean methane content (%)	Standard deviation	95% Confidence Interval
35	62	6	(57, 67)
40	68	7	(62, 74)
45	60	8	(53, 67)
ANOVA	$F(2, 27) = 3.14, p = 0.057$		

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This chart provides a comparison of the mean levels of methane found in biogas generated at varying temperatures of operation, as well as the standard variation and confidence interval for each mean value. According to the results of the analysis of variance (ANOVA), there is not a substantial difference in the amount of methane present across the spectrum of operating temperatures ($F(2, 27) = 3.14$, $p = 0.057$).

Table 8. Comparison of biogas production rates between different inoculum concentrations

Inoculum concentration (%)	**Mean biogas production rate (L/day)**	**Standard deviation**	**95% Confidence Interval**
2	30	4	(26, 34)
5	50	6	(44, 56)
10	60	8	(52, 68)
ANOVA	$F(2, 27) = 11.24$, $p < 0.001$		

This chart provides a comparison of the mean rates of methane generation for various inoculum concentrations, as well as the standard variation and confidence interval for each mean value. The results of the analysis of variance indicate that there is a significant difference in the rates of methane generation between the various concentrations of the inoculum (F(2, 27) = 11.24, p 0.001).

Table 9. Comparison of biogas quality between different pH levels

pH level	**Mean methane content (%)**	**Standard deviation**	**95% Confidence Interval**
6.5	65	5	(60, 70)
7.0	63	7	(56, 70)
7.5	57	6	(51

In order to evaluate the performance of the suggested bioreactor for the effective conversion of agricultural refuse into sustainable energy, one essential aspect that must be considered is the comparison of the rates of methane generation between the various feedstocks. According to the fictitious data that was presented, Feedstock A, which is made up of maize stover and bovine manure, had the greatest methane generation rate, with an average of 0.83 m3 CH4 per kg of VS that was introduced. Feedstock B, which is made up of rice straw and pig excrement, had the second-highest methane production rate, with an average of 0.68 m3 CH4/kg VS added. This feedstock also had the second-highest methane production rate. Feedstock C, which is made up of wheat straw and poultry excrement, had the lowest rate of methane generation, with an average of 0.52 m3 CH4 produced for every kilogram of VS that was introduced.

Based on these findings, it appears that the composition of the substrate plays a significant part in establishing the pace at which methane is produced. It would appear that corn stover and bovine excrement are the most efficient feedstocks for the generation of methane. This is likely due to the high levels of readily metabolized organic matter that both of these materials contain. Li et al. (2022) Rice chaff and pig excrement both exhibited a comparatively high rate of methane generation, which can most likely be attributed to the middling amounts of organic matter that both of these materials contained. On the other hand, wheat straw and poultry manure had the lowest methane generation rate. This could be because of the reduced organic matter composition of wheat straw and chicken manure, or it could be due to the existence of inhibitors that restrict the activity of the microbial population.

According to these findings, obtaining optimum bioreactor performance and optimizing energy production requires careful consideration of a number of factors, one of which is the selection

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and preparation of feedstock. It is necessary to conduct additional research in order to investigate the possibilities of various ingredient combinations and to perfect the circumstances of the bioreactor in order to achieve even greater rates of methane generation (Safarudin et al., 2018). In general, the comparison of the rates of methane production between the various feedstocks offers beneficial insights into the possibilities of the suggested bioreactor for the effective and sustainable conversion of agricultural refuse to renewable energy.

When evaluating the performance of the suggested bioreactor for the effective conversion of agricultural refuse into sustainable energy, one of the most important aspects that must be considered is the evaluation of the quality of the methane produced at various operating temperatures. According to the fictitious data that was presented, the biogas that was generated at an operating temperature of 37 degrees Celsius had an average methane concentration that was 68.5% higher than the other temperatures. The biogas that was generated when the operating temperature was set to 42 degrees Celsius had an average methane concentration of 61.3%, making it the second-highest of its kind. The biogas that was generated when the operating temperature was set to 47 degrees Celsius had an average methane concentration that was 56.8 percent lower than the other biogas.

Based on these findings, it appears that the temperature at which the biogas production process is carried out plays a substantial part in determining the quality of the biogas that is generated. In general, greater temperatures result in a higher methane concentration. The temperature of approximately 37 degrees Celsius appears to be the optimum operating temperature for optimizing methane generation as well as the quality of biogas, with a decrease in methane concentration being observed at both higher and lower temperatures.

According to these findings, determining the correct temperature at which the bioreactor should operate is one of the most important steps in the process of optimizing energy production and obtaining the best possible performance from the bioreactor. In addition, the findings indicate that the methane generated at greater temperatures may require additional processing in order to enhance its quality and rid it of any contaminants before it can be used as a source of sustainable energy.

Comparing the quality of the biogas produced at different temperatures reveals important information about the capabilities of the proposed bioreactor to convert waste from agricultural production into a form that can be used to generate renewable energy in an effective and environmentally responsible manner. Additional study is required to maximize the operating circumstances and investigate the bioreactor's potential for producing biogas with an even greater methane concentration.

The evaluation of the performance of the suggested bioreactor for the effective conversion of agricultural refuse to sustainable energy involves a number of factors, one of the most significant of which is the comparison of the rates of methane production between different inoculum concentrations. According to the fictitious data that was presented, it would appear that the bioreactor that was inoculated with a 20% inoculum concentration had the greatest methane production rate with an average of 0.7 L per day. The bioreactor that was seeded with an inoculum concentration of 10% had a slower rate of methane generation, coming in at an average of 0.5 liters per day. The bioreactor that was inoculated with a concentration of inoculum equal to 5% had the slowest rate of methane generation, coming in at an average of 0.3 liters per day.

Based on these findings, it appears that the concentration of the inoculum is an essential element that plays a role in establishing the rate at which biogas is produced, with a greater

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inoculum concentration leading to a higher rate of biogas production. It is important to note, however, that the difference in the rate of biogas production between the 20% and 10% inoculum concentrations was not nearly as substantial as the difference in the rate of biogas production between the 10% and 5% inoculum concentrations.

The construction and functioning of the suggested bioreactor are both significantly impacted by these discoveries, which have important consequences. To be more specific, they imply that increasing the inoculum concentration may be advantageous for increasing the rates of methane production as well as the total amount of energy produced. However, when choosing an appropriate concentration, it is also essential to take into consideration the price as well as the accessibility of the inoculum.

In conclusion, the comparison of the rates of biogas production between the various inoculum concentrations offers important insights into the possibilities of the suggested bioreactor for the effective and sustainable conversion of agricultural refuse into renewable energy. Additional study is required to determine the optimal concentration of the inoculum and to investigate the capacity of the bioreactor to generate methane at production rates that are significantly higher than those currently achieved.

Conclusion

According to the findings of the research, there are a number of aspects that can have an effect on the efficiency of the bioreactor. These aspects include the choice and preparation of the substrate, the operating temperature, the inoculum concentration, and the hydraulic retention duration. The comparison of the rates of methane production between various feedstocks, the quality of biogas produced at various temperatures of operation, and the rates of biogas production at various inoculum concentrations has provided useful insights into the potential of the proposed bioreactor for the efficient and sustainable conversion of agricultural waste to renewable energy. The significance of the research that is described in this article is brought to light by the conversation. The data analysis and comparison presented in this research demonstrate the possibility of an innovative bioreactor for effective conversion of agricultural refuse to sustainable energy.

Based on the findings of the study that compared the rates of methane production between various feedstocks, it was determined that some feedstocks, such as maize stover and wheat straw, have a greater possibility for the production of biogas than others. When the quality of biogas was compared across a range of different operating temperatures, it was found that higher temperatures led to a higher methane concentration in the biogas, despite the fact that this was accompanied by a reduction in the amount of biogas production. When the rates of biogas production were compared across a range of different inoculum concentrations, it was discovered that higher inoculum concentrations led to a greater amount of biogas production but also a shorter period of hydraulic retention time.

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