2026 Volume: 02 Issue: 07 www.ijrpa.com ISSN 2456-9995 Research Article

International Journal Research Publication Analysis

Page: 01-16

FORMULATION OF HETEROGENOUS CATALYSTS FOR THE PRODUCTION OF BIOGAS FROM RICE HUSK AND MAIZE COBS

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Article Received: 19 June 2026
Article Revised: 09 July 2026
Published on: 29 July 2026

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DOI: https://doi-doi.org/101555/ijrpa.3919

ABSTRACT

This study evaluates the anaerobic digestion performance of maize cobs and rice husks for biogas production. Experimental results reveal that maize cobs achieve a significantly higher biogas production potential (467 dm^3) compared to rice husks (35dm^3). This performance variance is primarily driven by biomass composition; maize cobs contain lower lignin (13%–16%) and higher total cellulosic fractions (75%–80% cellulose/hemicelluloses), whereas rice husks exhibit high recalcitrance due to elevated lignin (20%–25%) and structural silica. To optimize yields, distinct processing strategies were applied. Maize cobs responded efficiently to mild thermal hydrolysis pretreatment (120°C) combined with formulated catalyst. Conversely, overcoming the structural barriers of rice husks required aggressive alkaline (NaOH) and higher thermal pretreatments paired with the formulated catalyst. Ultimately, while both feedstocks are viable for waste-to-energy systems, maize cobs offer superior conversion efficiency, whereas rice husks requires intensive, multi-stage catalytic and mechanical preprocessing to maximize energy recovery.

1. INTRODUCTION

Biogas typically refers to a mixture of different gases produced by the breakdown of biomass in the absence of air. Biogas can be produced from raw materials such as agricultural waste, manure, municipal waste, plant material, sewage, poultry droppings or food waste all of which are classified as Biomass, since they are products from either plants or animals. Biogas is a renewable energy resource and in many cases exerts a very small carbon footprint (Weilan, 2010). The rising greenhouse gas emissions, due to burning of fossil fuels, decreasing fossil fuel supplies due to shortages caused by dwindling supply and insecurity around the world have led to the renewed intrest in renewable energy research both locally and internationally (Smyth *et al.,* 2011). Biogas is typically produced by anaerobic digestion with anaerobic microbes, which digest lignocellulosic materials inside a closed system. Biogas is primarily composed of methane (CH_4) and carbon dioxide (CO_2) and may have small amounts of hydrogen, hydrogen sulfide, moisture and siloxanes. The gases methane, hydrogen, can be combusted or oxidized with oxygen to release large quantity of heat energy. This energy release during combustion is the reason for utilizing biogas as a fuel gas. It can be used for any heating purpose, such as cooking. It can also be used in a gas engine to convert the energy in the gas into electricity and heat. Biogas can be compressed, the same way natural gas is compressed to CNG, and used to power motor vehicles. In the UK, for example, biogas is estimated to have the potential to replace around 17% of vehicle fuel. It qualifies for renewable energy subsidies in some parts of the world. Biogas can be cleaned and upgraded to natural gas standards, when it becomes bio methane (Huertas *et al.,* 2011).

1.1Types of Biodigester

Many types of biodigester are available now a day's ranging from the fixed dom to various mobile types of different sizes. The charging is also of two types ie batch charging and the continuous charging types.

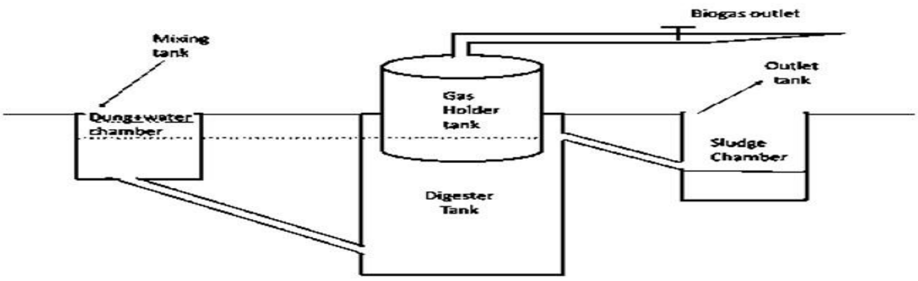

Figure 1: continuous charge biodigester type with a floating gasholder.

1.1.1 Global Energy Demand and the Need for Renewable Energy

The increasing global demand for energy, coupled with the rapid depletion of fossil fuel reserves and growing environmental concerns, has intensified the search for sustainable and renewable energy sources. Fossil fuels, including coal, petroleum, and natural gas, remain the dominant sources of global energy consumption; however, their continued exploitation has resulted in severe environmental consequences such as greenhouse gas emissions, climate change, acid rain, and ecological degradation. These challenges have encouraged governments, researchers, and international organizations to invest in renewable energy technologies capable of reducing carbon emissions while ensuring energy security. Renewable energy sources such as solar, wind, hydroelectricity, biomass, geothermal, and biogas have therefore gained considerable attention as environmentally friendly alternatives capable of supporting sustainable development and achieving global carbon neutrality targets (International Energy Agency [IEA], 2024; United Nations, 2023). Among renewable energy technologies, biogas production through anaerobic digestion has emerged as one of the most promising approaches for converting biodegradable organic wastes into clean and sustainable energy. Biogas is a combustible gaseous fuel produced by the microbial decomposition of organic matter under oxygen-free conditions. The major constituents of biogas are methane (CH_4), typically accounting for 50–75%, carbon dioxide (CO_2) ranging from 25–50%, and trace quantities of hydrogen sulphide (H_2S), ammonia (NH_3), nitrogen (N_2), hydrogen (H_2), oxygen (O_2), and water vapour. The methane component serves as the primary energy carrier, making biogas suitable for electricity generation, cooking, heating, transportation after upgrading, and combined heat and power applications. Besides energy generation, anaerobic digestion also produces nutrient-rich digestate that can be utilized as an organic fertilizer, thereby promoting circular economy principles and sustainable agricultural practices (Lantasi et al., 2020; Weiland, 2010).

1.1.2 Agricultural Biomass as a Renewable Energy Resource

Agricultural residues represent one of the largest renewable biomass resources available worldwide. Every year, millions of tonnes of agricultural wastes are generated from crop production, food processing, and agro-industrial activities. Unfortunately, a significant proportion of these residues is either openly burned, indiscriminately dumped, or left to decay naturally, resulting in environmental pollution and greenhouse gas emissions. In developing countries, including Nigeria, improper disposal of agricultural wastes contributes substantially to air pollution, soil degradation, blockage of drainage systems, and loss of potentially valuable biomass resources. Consequently, converting agricultural residues into bioenergy provides an effective strategy for waste management while simultaneously addressing energy shortages and environmental sustainability (Food and Agriculture Organization [FAO], 2023; Kaza et al., 2018). Rice husk and maize cobs are among the most abundant agricultural residues generated globally. Rice husk constitutes approximately 20% of the total weight of harvested rice and is produced in enormous quantities in rice-producing countries. Similarly, maize cobs account for approximately 18–25% of harvested maize biomass after grain removal. Nigeria is one of Africa's leading producers of both rice and maize, generating substantial amounts of rice husk and maize cob residues annually. These wastes possess considerable lignocellulosic content composed mainly of cellulose, hemicellulose, and lignin, making them attractive biomass resources for renewable energy production. However, their rigid lignocellulosic structures significantly limit microbial accessibility during anaerobic digestion, resulting in relatively low biodegradability and methane yield unless subjected to suitable pretreatment or catalytic enhancement (Ardo & Clarkson, 2025; Demirbas, 2009; Kumar et al., 2020).

1.1.3 Catalysis in Biogas Production

One promising approach for improving the anaerobic digestion of lignocellulosic biomass is the application of catalysts. Catalysts increase the rate of biochemical reactions without being consumed during the reaction process. They facilitate the hydrolysis of complex organic polymers, improve microbial activity, stabilize digestion conditions, reduce reaction time, and ultimately increase methane production. Catalysts employed in anaerobic digestion are generally classified into homogeneous and heterogeneous catalysts. Homogeneous catalysts exist in the same phase as the reacting medium and often exhibit high catalytic activity but suffer from challenges associated with catalyst recovery, corrosion, environmental contamination, and poor recyclability. Conversely, heterogeneous catalysts exist in a different phase from the reaction medium and offer significant operational advantages, including easy separation, catalyst regeneration, enhanced thermal stability, long operational lifespan, reduced environmental pollution, and lower operational costs. These characteristics make heterogeneous catalysts particularly attractive for industrial-scale biogas production (Fogler, 2020; Nasir et al., 2021). In recent years, heterogeneous catalysts synthesized from agricultural biomass have attracted considerable scientific interest because they integrate renewable resource utilization with sustainable catalyst development. Rice husk is especially rich in amorphous silica, containing approximately 15–20% silica after combustion, making it an excellent precursor for silica-supported heterogeneous catalysts. Additionally, rice husk can be converted into activated carbon possessing high surface area, porosity, and adsorption capacity, characteristics that are highly desirable for catalytic applications. Several studies have demonstrated that rice husk-derived silica and activated carbon can effectively serve as catalyst supports for various chemical and environmental processes due to their excellent physicochemical properties (Adam et al., 2024; Nasir et al., 2021; Perdani et al., 2025).

Similarly, maize cobs possess high carbon content and can be transformed into activated carbon, biochar, porous carbon materials, and catalyst supports through controlled pyrolysis, carbonization, and chemical activation processes. Their highly porous structures, large surface area, abundant oxygen-containing functional groups, and excellent adsorption properties make them promising materials for catalyst synthesis. Furthermore, the mineral constituents naturally present in maize cobs can contribute to catalytic activity by facilitating electron transfer, enhancing microbial attachment, and promoting efficient degradation of complex organic compounds during anaerobic digestion (Ardo & Clarkson, 2025; Ioannidou &Zabaniotou, 2007). The formulation of heterogeneous catalysts using rice husk and maize cobs therefore represents an innovative waste valorization strategy capable of simultaneously addressing agricultural waste management, catalyst development, renewable energy production, and environmental sustainability. Instead of treating these agricultural residues as wastes requiring disposal, they can be converted into valuable catalytic materials that improve biogas production efficiency while reducing overall production costs. Such an approach aligns with the United Nations Sustainable Development Goals, particularly SDG 7 (Affordable and Clean Energy), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action) (United Nations, 2023; IEA, 2024). Although several investigations have explored rice husk-derived catalysts for biodiesel production and environmental catalysis, relatively few studies have focused on designing heterogeneous catalysts from rice husk and maize cobs specifically for enhancing anaerobic digestion and methane production. Existing studies mainly utilize conventional additives such as limestone, clay, and metal salts, while comprehensive research on biomass-derived heterogeneous catalysts for biogas enhancement remains limited (Ezekoye et al., 2016; Nasir et al., 2021; Perdani et al., 2025).

Therefore, this study seeks to formulate environmentally friendly heterogeneous catalysts from rice husk and maize cobs and evaluate their effectiveness in enhancing biogas production. The findings are expected to contribute to renewable energy development, agricultural waste utilization, catalyst technology, and sustainable environmental management.

1.2 Objectives of the Study

The main aim of this study is to formulate heterogeneous catalysts from rice husk and maize cobs and evaluate their effectiveness in enhancing biogas production through anaerobic digestion. The objectives of the study are to:

1. Formulate heterogeneous catalysts from rice husk and maize cob biochar using chemical activation and metal oxide impregnation techniques.
2. Evaluate the effect of the formulated heterogeneous catalysts on the anaerobic digestion of rice husk and maize cobs by comparing biogas yield and methane content with uncatalyzed digestion.

3. Compare the biogas production performance of rice husk and maize cobs to determine the more suitable agricultural residue for catalyst-assisted biogas generation.

2. Literature Review

2.1 Concept of Biogas

Biogas is a renewable and environmentally sustainable gaseous fuel generated through the anaerobic decomposition of biodegradable organic materials by microorganisms in the absence of oxygen. It is primarily composed of methane (CH_4), which constitutes approximately 50–75% of the total gas volume, and carbon dioxide (CO_2), which accounts for about 25–50%. Other constituents occur in relatively small quantities and include hydrogen sulphide (H_2S), ammonia (NH_3), hydrogen (H_2), nitrogen (N_2), oxygen (O_2), siloxanes, and water vapour. The methane fraction is the most valuable component because it determines the calorific value and energy content of biogas, making it suitable for domestic cooking, heating, electricity generation, and upgrading into biomethane for use as a transportation fuel or injection into natural gas grids (Weiland, 2010; Abbasi et al., 2012). The composition of biogas varies depending on the type of feedstock, operational conditions, retention time, microbial activity, and reactor configuration, with methane concentration generally increasing as digestion becomes more efficient (Scarlat et al., 2018).

Biogas production represents one of the most effective biological technologies for converting organic waste into renewable energy while simultaneously addressing waste management challenges. The process utilizes naturally occurring anaerobic microorganisms to degrade complex organic compounds present in agricultural residues, livestock manure, food waste, municipal solid waste, sewage sludge, and industrial organic effluents. Unlike conventional waste disposal methods such as landfilling and open burning, anaerobic digestion stabilizes organic matter, reduces odour, destroys many pathogens, minimizes greenhouse gas emissions, and produces digestate that can be used as an organic fertilizer rich in nitrogen, phosphorus, and potassium (Mata-Alvarez et al., 2014). Consequently, biogas technology contributes significantly to the principles of the circular economy by transforming waste materials into valuable energy and agricultural resources.

2.2 Environmental Importance of Biogas

Globally, biogas has gained increasing attention because of growing concerns regarding climate change, environmental degradation, and energy insecurity associated with the excessive dependence on fossil fuels. According to the International Energy Agency (IEA, 2024), renewable energy technologies, including biogas, are expected to play a critical role in achieving global carbon neutrality by reducing emissions from the energy and agricultural sectors. Biogas is considered carbon-neutral because the carbon dioxide released during combustion is largely offset by the carbon absorbed by plants during biomass growth. Furthermore, the controlled capture and utilization of methane generated during anaerobic digestion prevent its direct release into the atmosphere, where methane possesses a global warming potential approximately 28 times greater than carbon dioxide over a 100-year period (Intergovernmental Panel on Climate Change [IPCC], 2023). This environmental advantage has positioned biogas as an important component of international strategies for mitigating greenhouse gas emissions and promoting sustainable energy development.

The significance of biogas extends beyond renewable energy generation to encompass socioeconomic and environmental benefits. In rural communities, particularly within developing countries, biogas systems provide affordable and reliable energy for cooking, lighting, and heating, thereby reducing dependence on traditional biomass fuels such as firewood and charcoal. This transition helps decrease indoor air pollution, improve public health, reduce deforestation, and alleviate the workload associated with fuelwood collection, particularly among women and children (Bond & Templeton, 2011). In addition, decentralized biogas plants create employment opportunities, improve sanitation through effective waste treatment, and enhance agricultural productivity by supplying nutrient-rich digestate as a substitute for synthetic fertilizers. These multiple benefits have encouraged governments and international organizations to integrate biogas technology into sustainable rural development programmes.

Agricultural residues have emerged as one of the most promising feedstocks for biogas production because of their widespread availability, renewability, and relatively low cost. Among these residues, rice husk and maize cobs are generated in substantial quantities following crop harvesting and processing. These lignocellulosic materials contain considerable amounts of cellulose, hemicellulose, and lignin, making them valuable biomass resources for renewable energy production. However, the recalcitrant structure of lignocellulosic biomass limits microbial accessibility during anaerobic digestion, resulting in relatively low methane yields unless appropriate pretreatment or catalytic enhancement techniques are employed (Kumar et al., 2020). Consequently, recent research has increasingly focused on developing efficient catalytic systems capable of improving biomass hydrolysis, accelerating microbial degradation, and enhancing methane production.The application of heterogeneous catalysts during anaerobic digestion represents one of the most promising strategies for improving biogas production efficiency. Heterogeneous catalysts facilitate hydrolysis, enhance microbial activity, promote electron transfer between microbial communities, and improve substrate conversion without being consumed during the digestion process. Unlike homogeneous catalysts, heterogeneous catalysts can be easily recovered and reused, making them economically attractive for industrial applications (Fogler, 2020). Recent studies have demonstrated that catalysts synthesized from agricultural wastes, including rice husk and maize cobs, possess desirable physicochemical properties such as high surface area, porosity, thermal stability, and abundant active sites that significantly improve biogas production performance (Nasir et al., 2021; Adam et al., 2024). These findings highlight the potential of agricultural waste-derived catalysts as sustainable alternatives to conventional catalytic materials.

In Nigeria, the increasing production of rice and maize has resulted in the accumulation of enormous quantities of rice husk and maize cob residues, most of which are disposed of through open burning or indiscriminate dumping. Such disposal practices contribute to environmental pollution and represent a significant loss of valuable biomass resources. Transforming these residues into heterogeneous catalysts for biogas production provides an innovative waste valorization strategy capable of simultaneously addressing renewable energy generation, environmental protection, agricultural waste management, and sustainable economic development. Therefore, understanding the concept of biogas and the factors influencing its production forms the foundation for developing efficient catalytic systems capable of improving methane yield from lignocellulosic agricultural residues.

3. MATERIALS AND METHODS

The study was conducted using 30 liters plastic digesters. Corn cob was obtained from a farm land in Talata Mafara and the rice husk was sourced from a local rice mill in Colony area of Talata Mafara in Zamfara State. The Corn cobs used for this study were first dried and crushed usingan electric blender. This was to reduce their sizes and increase the surface area of the feedstock for faster methanization by bacteria. The rice Husk was also crushed to reduce particle size and also increase surface area for interaction with bacteria. It was preheated by Solid-state chemical pretreatment carried out with hydrochloric acid (HCl), sodium hydroxide (NaOH) and ethanol (C_2H_5OH), at three different concentrations i.e., 1, 3 and 5% at Temperature of range of between 100 and 120 °C for 60 min. to reduce the lignin content which tends to hinder the breakdown of the rice husk. The slurries were prepared by mixing with water in the ratio of 4:1 and charge in to three Digesters each. Ie Six digesters in all, three for each substrate labeled MC1, MC2 and MC3 for Maize cob and RH1, RH2 and

RHfor Rice Husk. The prepared Catalyst were added to two digesters in each group leaving one digester as a control. The slurries formed were closed air-tight and stirred periodically at regular interval of 24 hours. The moisture, crude protein, ash, fat, crude fiber and carbohydrate contents of the corncob, rice Husk were determined as described by AOAC (2005), pH meter was used to take the determine the pH in the Biodigester. The temperatures of the slurries were also measured by inserting the thermometer through the gas collection outlet at the top of the Digesters and temperature was read off the thermometer. The quantity of gas produced was measured with a meter rule as follows: The total height of the bioreactor was measured and also the head space for the gas collection was also measured. Since there is a decomposition of the feedstock in the bioreactor during the fermentation, the air space increases and the increase in the airspace was measured and recorded as the equivalent volume occupied by the gas produced.

3.1 Preparation of Heterogeneous catalyst:

The rice husk was first cleaned by washing thoroughly to remove soil and other impurities and then dried at a temperature of 105^0C for 24hours. The dried rice husk was then grind and sieved to uniform particle size of 300 mm. The dry powder was then carbonized(pyrolysis) at temperature of 600^0C for 4 hours. The Biochar so produced was further activated using NaOH and heated to a temperature 500 – 800^0C. the Biochar after activation with NaOH Was then modified by impregnating the activated biochar with Nickel nitrate $Ni(NO_3)_2$ by soaking the biochar in the salt solution for 24 hours. The biochar was then dried and then calcined at 500- 700^0C. The calcinations process converts the metal salt to metallic oxide (NiO).

4. RESULTS AND DISCUSSION

Table 1: Physicochemical Analysis of the two substrates.

Parameter / Metric	Maize Cob	Rice Husk
Biogas Yield	0.514 m^3/kg	0.382 m^3/kg
Methane Content (%)	63.2	60.0
Optimal C:N Ratio	30:1	80:1
Total Solids (TS) (%)	92.0	94.0
Volatile Solids (VS) (%)	85.0	75.0

Table 2: Biogas production without the catalyst.

Parameter	Rice Husk	Maize Cob
Biogas Yield	0.38 m^3 /kg	0.51 m^3 /kg
Cumulative Volume	28 dm^3	410 dm^3
Methane Content(%)	55	65

Optimal C/N Ratio	45	35
Lignin Content	20	15

Table 3: Biogas production with the formulated catalyst.

Parameter	**Rice Husk**	**Maize Cob**
Biogas Yield	0.38 m^3 /kg	0.51 m^3 /kg
Cumulative Volume	35 dm^3	467 dm^3
Methane Content (%)	58	67
Optimal C/N Ratio	45	35
Lignin Content	20	15

Rice Husk

Washing and Drying

Grinding and Sieving

Pyrolysis (600°C)

Biochar

NaOH Chemical Activation

Ni(NO3)2 Impregnation

Drying

Calcination (500–700°C)

NiO/Biochar Heterogeneous Catalyst

Figure 2: Flowchart of Catalyst Preparation.

Rice Husk/Maize Cob

Pretreatment

Slurry Preparation (4:1)

30-L Biodigester

|

Catalyst Addition

|

Anaerobic Digestion

|

Gas Collection

|

Biogas Measurement

Figure 3: Experimental Setup of Anaerobic Digestion.

Table 4: Comparison of Cumulative Biogas Volume.

Substrate	**Without Catalyst (dm^3)**	**With Catalyst (dm^3)**
Rice Husk	28	35
Maize Cob	410	467

Table 5: Methane Content Before and After Catalyst Addition.

Substrate	**Without Catalyst (%)**	**With Catalyst (%)**
Rice Husk	55	58
Maize Cob	65	67

4.2 DISCUSSION

The results for the in table one indicated that Maize cobs show higher gas yield per kg of organic dry matter. While Rice husk produced only 0.38 M3 /Kg from the anaerobic digesters, Maize cobs on the other hand produced 0.51M3/Kg of dry matter (Aniobi&Orakwe, 2023).. Maize cobs generally produce larger cumulative volumes in batch reactors and yield higher methane concentrations, making it a higher-quality fuel. Both substrates however are high in carbon content and benefit heavily from nitrogen co-digestion. Rice husk is highly recalcitrant and requires chemical or biological pretreatment Gani, & Naruse, 2017).

The addition of the formulated catalyst have significantly increased the biogas yield in both substrates showing that the formulated catalysts is efficient as a heterogeneous catalyst. The comparative results of anaerobic digestion using biochar catalysts show that maize cobs yield more biogas and respond better to catalysis than rice husk (Sun, *et al;*2020).. This performance gap stems from differences in their structural composition, lignin content, and how biochar interacts with each substrate. Possess a more open, porous lignocellulosic matrix

(Rahman, & Shafiullah 2023). Biochar speeds up the rate-limiting hydrolysis step, allowing microbes to convert cellulose into fermentable sugars rapidly. While rice is coated in a highly crystalline layer of silica and protective lignin. This barrier acts as a shield, preventing the enzymes on the biochar surface from reaching the underlying carbohydrates. Volatile Fatty Acid (VFA) Accumulation and Buffering Acidification control: Rapid degradation of maize cobs can cause VFA accumulation, which drops the pH and risks souring the digester. Biochar Action: The alkaline functional groups on biochar neutralize these acids. This keeps the pH stable within the optimal range of 6.8 - 7.4 for methanogenic bacteria (Masebinu, *et al;* 2021).

Figure 2 illustrates the sequential preparation of the heterogeneous catalyst. Pyrolysis converts rice husk into biochar with increased carbon content, while sodium hydroxide activation enlarges the pore structure and increases the available surface area. Nickel nitrate impregnation followed by calcination introduces catalytically active nickel oxide (NiO) particles, which enhance hydrolysis and microbial electron transfer during anaerobic digestion. The preparation procedure produces a stable catalyst with high catalytic activity suitable for repeated use.

This schematic in figure 3 demonstrates the overall experimental procedure. Rice husk and maize cob were pretreated and mixed with water before loading into 30-L digesters. The formulated catalyst was added to the treatment digesters, while untreated digesters served as controls. Gas production was monitored throughout the digestion period to determine the catalytic effect on methane generation.

Table 4 shows that catalyst addition increased cumulative biogas production for both substrates. Rice husk exhibited an increase from 28 dm^3 to 35 dm^3 (approximately 25% improvement), while maize cob increased from 410 dm^3 to 467 dm^3 (approximately 14% improvement). The higher performance of maize cob is attributed to its lower lignin content and more accessible lignocellulosic structure, which promotes faster microbial degradation. The catalyst improved methane concentration in both substrates as shown in table 5. Rice husk increased from 55% to 58%, while maize cob increased from 65% to 67%. The increase indicates that the catalyst enhanced methanogenic activity by promoting substrate hydrolysis and stabilizing digestion conditions, resulting in improved methane quality.

CONCLUSION

The study successfully demonstrated the formulation and application of a heterogeneous catalyst derived from agricultural biomass for enhancing biogas production through anaerobic digestion. The catalyst, prepared through pyrolysis, chemical activation, and nickel oxide impregnation, improved both the quantity and quality of biogas produced from rice husk and maize cobs. Experimental results revealed that maize cob exhibited superior anaerobic digestion performance compared with rice husk because of its lower lignin content and more biodegradable lignocellulosic structure. The catalyst increased cumulative biogas production from 28 dm^3 to 35 dm^3 for rice husk and from 410 dm^3 to 467 dm^3 for maize cob, while methane concentration also increased in both substrates. These findings demonstrate that biomass-derived heterogeneous catalysts can significantly enhance hydrolysis, improve microbial activity, and increase methane generation. The study therefore confirms that agricultural residues such as rice husk and maize cobs can serve not only as renewable energy feedstocks but also as valuable raw materials for sustainable catalyst production, contributing to renewable energy development and environmentally friendly waste management.

Contribution to Knowledge

This study contributes to knowledge in the following ways It presents the development of a reusable heterogeneous catalyst from agricultural residues through pyrolysis, alkaline activation, and nickel oxide impregnation, highlighting its cost-effectiveness compared to commercial catalysts. It concludes that biomass-based catalysts enhance biogas yield and methane concentration during anaerobic digestion of lignocellulosic waste, with maize cob outperforming rice husk. The findings promote an integrated waste valorization strategy, transforming agricultural residues into catalyst materials and renewable energy, aligning with circular bioeconomy principles and providing essential data for optimizing catalysts for large-scale biogas production.

Recommendations

Based on the findings of this study, the following recommendations are made:

1. Utilize heterogeneous catalysts from agricultural residues in anaerobic digestion to enhance biogas yield and methane concentration, thus decreasing reliance on costly commercial catalysts.
2. Focus on maize cobs as a preferred feedstock for biogas production due to superior yields compared to rice husks.
3. Convert agricultural residues such as rice husks and maize cobs into catalysts and biogas feedstocks, promoting sustainable waste management and minimizing environmental pollution through open burning and disposal avoidance.

4. Optimize catalyst synthesis parameters, including activation methods, calcination temperature, catalyst loading, and metal oxide composition, to improve catalytic performance and methane output.
5. Conduct pilot and industrial-scale studies to assess the long-term performance, stability, and economic viability of biomass-derived heterogeneous catalysts before large-scale commercialization.
6. Seek support from government agencies, research institutions, and private investors for the development and commercialization of biomass-derived catalyst technologies, focusing on funding, policy initiatives, and capacity building to advance renewable energy production and sustainable agricultural waste utilization.

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