

Original Research Article

Biogas Purification Using Rice Straw and Wood Chip Biochar

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Abstract: Non-renewable energy sources like coal, petroleum, and natural gas are depleting, and waste from biomass has become a problem dumping site for biogas production. Biogas purification, a sustainable and eco-friendly source of renewable energy, has the potential to be created through the manufacture of biogas from organic waste materials. However, biogas may be constrained by impurities, such as carbon dioxide (CO₂), which can cause damage to equipment and pipelines. Biochar materials like rice straw and wood chips have been suggested as strategies to remove CO₂ from biogas. This study aims to analyse the efficiency of rice straw and woodchip biochar for CO₂ removal from biogas and evaluate their potential as long-term and cost-effective biogas purification. Rice straw and woodchip biochar can be used as adsorbents to purify biogas and eliminate CO₂, enriched methane for various applications like energy generation, heating, and fuel. Biochar, a type of organic charcoal, selectively absorbs CO₂ from the biogas stream, allowing biomethane to flow through. The porous biochar's surface attracts and clings to CO₂ molecules in the biogas, drawing them out of the gas circulation. Due to variations in molecule size and polarity, biochar is selective for CO₂ over methane (CH₄), resulting in a gas stream enriched in CH₄. The biochar's high porosity and surface area make it an affordable, sustainable, and green material for biogas production.

Keywords: Biochar; Biogas; Rice straw; Wood chip; Adsorption

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1. Introduction

The main issues that have emerged in the environment in recent years are air pollution leading to global warming. This problem might be due to massive development of greenhouse gases (GHG) such as carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) that have

been produced because of extensive fossil fuel consumption and an increase in global population. (Azman *et al.*, 2023). It is commonly recognised that GHG plays a key role in global warming by influencing the amount of heat reflected off the Earth's surface, with CO₂ contributing the most (60%) and CH₄ having the least impact (15%). However, due to rapid depletion of fossil fuel resources brought on by their heavy use and the sharp fluctuations in the price of oil and fossil fuel energy sources, there is a growing movement towards discovering green energy alternatives that are both affordable and environmentally friendly (Abdeshahian *et al.*, 2016; Sáez-Martínez *et al.*, 2016). A combination of gases known as biogas is created when microorganisms consume organic material without the presence of oxygen. CH₄ and CO₂ make up most of it, although it may also contain trace amounts of other gases including hydrogen (H₂), nitrogen (N₂), and hydrogen sulphide (H₂S) (Mirmohamadsadeghi *et al.*, 2016). Biogas is a renewable energy source made from second-generation biomass waste conversion. Anaerobic digestion is a widely established pathway for biogas production from biomass and organic residues (Uçkun Kiran *et al.*, 2016; Yaqoob *et al.*, 2021). Biogas is the methane gas produced by the breakdown of biomass waste. Bioenergy derived from agricultural waste is thought to be capable of lowering methane emissions from organic sources and substituting fossil fuels (Lantasi *et al.*, 2020).

Adsorption is the process in which the adsorbate transfers from the fluid, including gas and liquid, to the adsorbent surfaces. It is mainly affected by two types of mechanisms, including physisorption (i.e., physical adsorption) and chemisorption (i.e., chemical adsorption). The physisorption is characterised by the diffusion of adsorbate into adsorbent surfaces, driven by physical forces resulting from concentration or pressure gradients. This mechanism is typically described by a weak interaction between adsorbate and adsorbent, which stems from intermolecular forces (e.g., Van der Waals forces). As expected for any physisorption processes outlined by the Le Chatelier principles, the adsorption capacity of biochar drops with the rise of adsorption temperature (Rashidi *et al.*, 2013; C. Wen *et al.*, 2023). In contrast, the chemisorption, however, is governed by chemical interactions between the adsorbate and adsorbent surfaces, and the electron transfer between adsorbate and surface functional groups in adsorbent forms chemical bonds. Generally, physisorption mainly occurs in either a monolayer or multilayer and is a reversible process, while chemisorption indicates that the adsorbate is chemically bonded with the adsorbent and thus tends to be non-reversible (Johari *et al.*, 2016; Wen *et al.*, 2023).

Among the various types of adsorbents, biochar is increasingly used for diverse environmental pollution remediation applications, including the removal of heavy metals

from aquatic environments because of its unique and excellent surface properties, such as porosity, surface functional groups, and mineral composition (Hopkins & Hawboldt, 2020; Shaheen *et al.*, 2019). Also, it is considered low-cost, renewable, and environmentally benign adsorbent (Willis *et al.*, 2017). The biosolid, as the stable carbon-rich solid by-product, is called biochar and hydrochar when it is derived from the hydrothermal carbonisation process. The biochar is not only capable of replacing coal as fuel in power plants but also utilised as cheap and effective gaseous adsorbent for the adsorption removal of flue gas pollutants such as sulphur dioxide (SO₂), nitrogen oxides (NO_x), CO₂, mercury (Hg), and volatile organic compounds (VOC). Its porous texture, high specific surface area, and ample surface functional groups and aromatic surfaces make it an excellent candidate for this application (Wen *et al.*, 2023).;

Biochar is an aromatic solid product and rich in carbon, which is prepared by high temperature pyrolysis of biomass, such as crop waste, municipal waste and animal faeces under the condition of hypoxia or micro-oxygen. Because of its wide source, large specific surface area, developed pores, strong stability and other characteristics, it is widely used in the fields of agriculture, environment, breeding and energy, , with its nutrient release, water-related properties and oxidation behaviour influenced by feedstock and production conditions (Liu *et al.*, 2019; Peterson & Brown, 2020; Werdin *et al.*, 2020). Concurrently, pyrolysis is widely used to produce biochar from biomass. The processing of biomass to obtain biochar enables the recovery of biomass and the regeneration of precious resources, which can effectively alleviate the problems associated with the increasing organic solid waste each year (Qiu *et al.*, 2022).

To encourage the production of biogas and other renewable energy sources, the government has implemented feed-in tariffs. The feed-in tariffs, which are in effect for 16 years from the start date, guarantee a price for power generated from biogas and supplied into the grid. By employing bio-CNG as a transportation fuel, using biogas as a sustainable energy source aids in lowering carbon emissions and improving urban air quality (Jain, 2016).

By 2025, Malaysia has set a goal of including 20% renewable energy in its energy mix. One possible source of this energy is biogas. Biogas may be created from a variety of organic waste sources, including municipal solid waste, agricultural waste, and palm oil mill effluent (POME). A biomethane upgrade is possible from the biogas generated, and this biomethane may be utilised in place of natural gas in a variety of industrial, transportation, and power production activities. Malaysia may decrease its reliance on fossil fuels, reduce greenhouse gas emissions, and advance sustainable development using biogas as a source of

renewable energy. The connectivity issue, technical difficulties, and a lack of space in biogas plants are only a few of the issues that must be resolved before Malaysia can fully realise the benefits of biogas (Amin *et al.*, 2022).

2. Materials and Methods

2.1. Rice Straw and Wood Chip

Wood chips and rice husks were procured from a local vendor. The wood chips originated from UPM Serdang, while the rice husks were sourced from Bintulu, Sarawak. Biochar is produced through a process called pyrolysis, which is the thermal decomposition of biomass in the absence of oxygen. The temperature is controlled from time to time, and the temperature can reach 800°C at a time. These wood chips and rice husk biochar were fed into a scrubber attached to the Anaerobic Digester (AD) tank and will act as an adsorbent of impurities of the gases that will be produced.

Adsorption is a surface phenomenon where molecules adhere to the surface of a solid material. Activated carbon and silica gel are prime examples of adsorbent materials. (Francis *et al.*, 2023). These substances attract and hold molecules on their surfaces, making them ideal for applications like air purification and chemical separation, while absorption involves the entire volume of the material. In this process, an absorbent soaks up the substance, penetrating deeply into the material (interpenetration of one phase into another). For example, gases or liquids will absorb into liquids.

The characteristics and properties of adsorbents include surface area; they have high surface areas, enhancing their ability to capture contaminants, porosity; the presence of numerous pores allows adsorbents to trap molecules efficiently and selectivity: many adsorbents attract specific molecules, making them versatile in various applications. Additionally, adsorbents have a high capacity to soak up liquids, making them effective for spill management. Other characteristics and properties of adsorbents are swelling; these materials often swell upon absorbing liquids, indicating their effectiveness and retention; adsorbents securely hold the absorbed substance, reducing the risk of leakage.



Figure 1. Rice Straw (left) and Wood Chip (right)

2.2. Biogas Production

Cow dung was taken from the Dairy Cattle and Ruminant Abattoir Complex Unit, UPM Bintulu Campus. For this research, about 20 kg of cow dung were collected. The cow dung was combined in an equivalent ratio to the water (1:1) to create slurry, which degrades anaerobically when water is added.

The anaerobic digester (AD) tank was filled with a combination of cow dung and water. The gas tank will be raised as it is filled with raw biogas in approximately 3 days. Next, the raw biogas was injected into the 2 L gas bag. For the first adsorbent sample, rice straw biochar was fed inside the scrubber column. Raw biogas was passed through a scrubber column containing adsorbent, then injected into the gas bag. After injecting the gas into the gas bag, rice straw biochar was taken out from the column and replaced with wood chip biochar as the second gas adsorbent sample. Next, the raw biogas and purified biogas samples were ready to be analysed using gas chromatography with flame-ionisation detection (GC-FID).

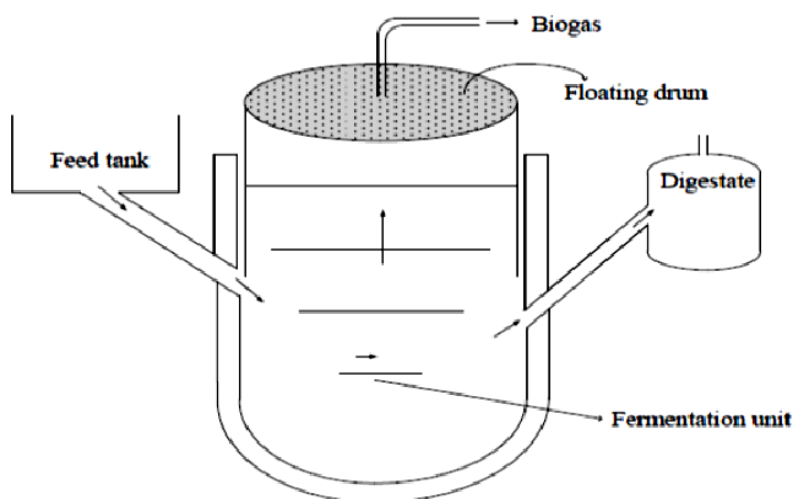


Figure 2. Schematic representation of a floating AD drum

2.3. Analysis method - GC-FID

The gases were analysed by GC-FID (Agilent 7890A gas chromatography) using a DB-1MS capillary column (0.25 mm I.D.; 0.25 µm film thickness). GC-FID is a technique to identify compounds based on retention time that converts into system-independent constants commonly known as the Retention index (or Kovats index). The retention indices of each chemical compound are calculated based on its retention time standardised to the retention times of nearby eluting n-alkanes (e.g., hexane, heptane, octane). In fact, retention times differ with the individual chromatographic system as it depends on the type and length of the column, film thickness, diameter, velocity and pressure of the carried gas and time consumed in the analysis. The derived retention indices are relatively independent of these parameters and allow comparing values measured by different analytical laboratories under varying conditions (Sarih *et al.*, 2021). Joulain and Wilfred (1998) believed that retention indices could help in the identification of components by comparing experimentally established retention indices with identified values. Despite the extensive studies and use of linear retention indices, one needs to be aware when using such indices in an absolute sense. Usually, data from one laboratory to another will commonly be accurately reproduced, though by combining with mass spectral results, retention data does still provide a good guide to discover the identities of components (Sarih *et al.*, 2021).

3. Results and Discussions

3.1. Adsorption of Gas

Gas adsorption is a critical process in the purification of gaseous streams, utilising materials with high surface area and porosity, such as biochar. In this study, gas chromatography with flame ionisation detection (GC-FID) was employed to analyse the adsorption efficiency before and after purification with biochar derived from rice straw and woodchips. Figure 3 and Table 1 indicate the composition and concentration of target gas components before any treatment. These baseline measurements serve to highlight the extent of impurities or undesired compounds present in the gas stream. The compounds that were identified include CO₂, O₂ and N₂, which show the largest area, indicating it is the most prominent component, while CO₂ has a lower area compared to O₂ and N₂, implying a smaller concentration in the mixture.

Figure 4 and Table 2 illustrate the impact of rice straw biochar on gas purification. The results demonstrate a notable reduction in the concentration of certain impurities, emphasising the biochar's effectiveness due to its specific surface area, pore structure, and

functional groups that facilitate adsorption. The retention times remain consistent between the "before purification" and "after purification" data, which confirms that the identified compounds are the same or comparable in identity. O₂ shows the highest area and height, indicating its prominence in the purified gas mixture, while CH₄ appears in the post-purification data but absent in the "before purification" results, suggesting a potential transformation or impurity introduction. Surface area and porosity are influenced by biochar feedstock, pyrolysis temperature, and the activation (Sajjadi *et al.*, 2018; Wen *et al.*, 2023).

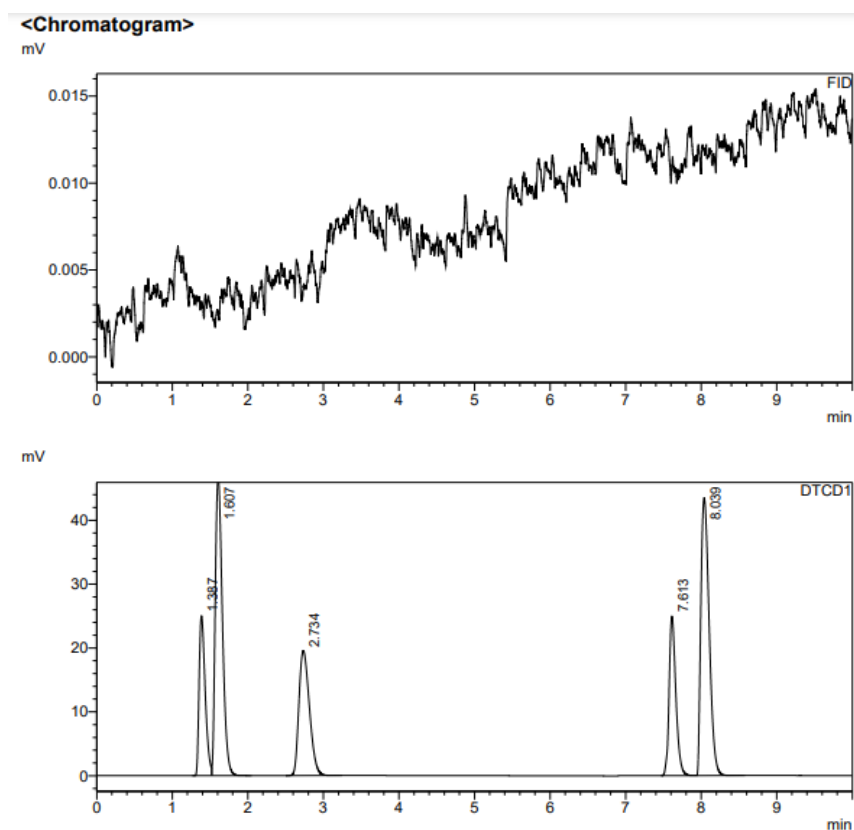


Figure 3. GC-FID reading before purification

Table 1. GC-FID reading before purification

Peak#	Ret. Time	Area	Height	Conc.	Unit	Mark	Name
1	1.387	140197	24961	0.000			
2	1.607	306599	46544	0.000		V	
3	2.734	188985	19500	0.000	%		CO2
4	7.613	154435	24912	0.000	%		O2
5	8.039	331280	43444	0.000	%	V	N2
Total		1121496	159361				

Figure 5 and Table 3 depict the purification performance of woodchip biochar. Compared to rice straw biochar, woodchip biochar exhibits variations in adsorption

efficiency, potentially attributable to differences in physical properties such as surface area and pore size distribution. The retention times remain consistent, which shows the same compounds are present before and after purification. O₂ continues to dominate, with the highest area. CH₄ shows a similarity to rice straw biochar purification, where CH₄ was present, while N₂ reappears here but with a significantly reduced area. Surface area and porosity, as the major physical properties, directly affect the sorption capacity. Gas adsorption analysis is commonly used for porosity and surface area measurements. In this process, solid material is exposed to vapours or gases at a variety of conditions (Sajjadi *et al.*, 2018).

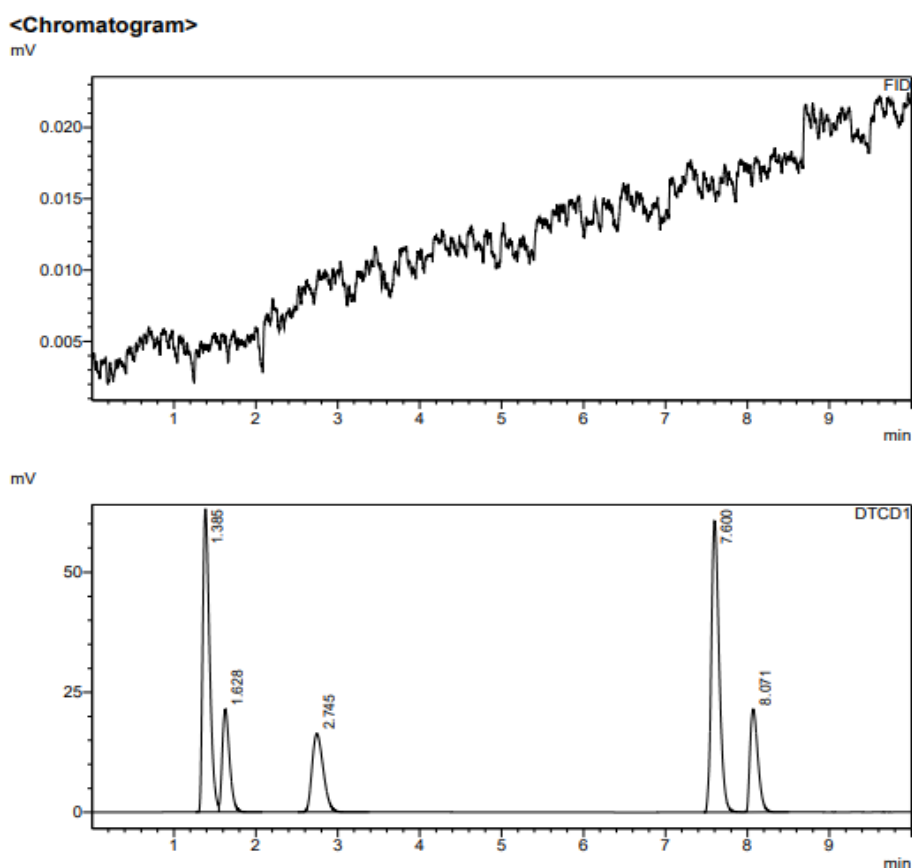


Figure 4. GC-FID reading after purification using rice straw biochar

Table 2. GC-FID reading after purification using rice straw biochar

DTCD1	Peak#	Ret. Time	Area	Height	Conc.	Unit	Mark	Name
	1	1.385	367534	62936	0.000			
	2	1.628	132954	21388	0.000		V	
	3	2.745	155759	16278	0.000			
	4	7.600	402950	60522	0.000	%		O ₂
	5	8.071	143728	21462	0.000	%	V	CH ₄
	Total		1202926	182585				

From the results, it can be concluded that before purification, N₂ was dominant with a high area and CH₄ was absent. After purification with rice straw biochar, CH₄ appeared, and the O₂ area increased significantly while the N₂ contribution decreased substantially. In the after purification with woodchip biochar, CH₄ remains present, with a smaller area compared to rice straw biochar purification. Meanwhile, the N₂ area dropped even further compared to its initial dominance, showing better purification potential for this compound. The results suggest that woodchip biochar is effective in reducing nitrogen gas (N₂) while retaining oxygen (O₂) at a high level. As for CH₄ retention, both biochar shows CH₄ after purification, likely indicating the catalytic formation or retention of CH₄ during the process.

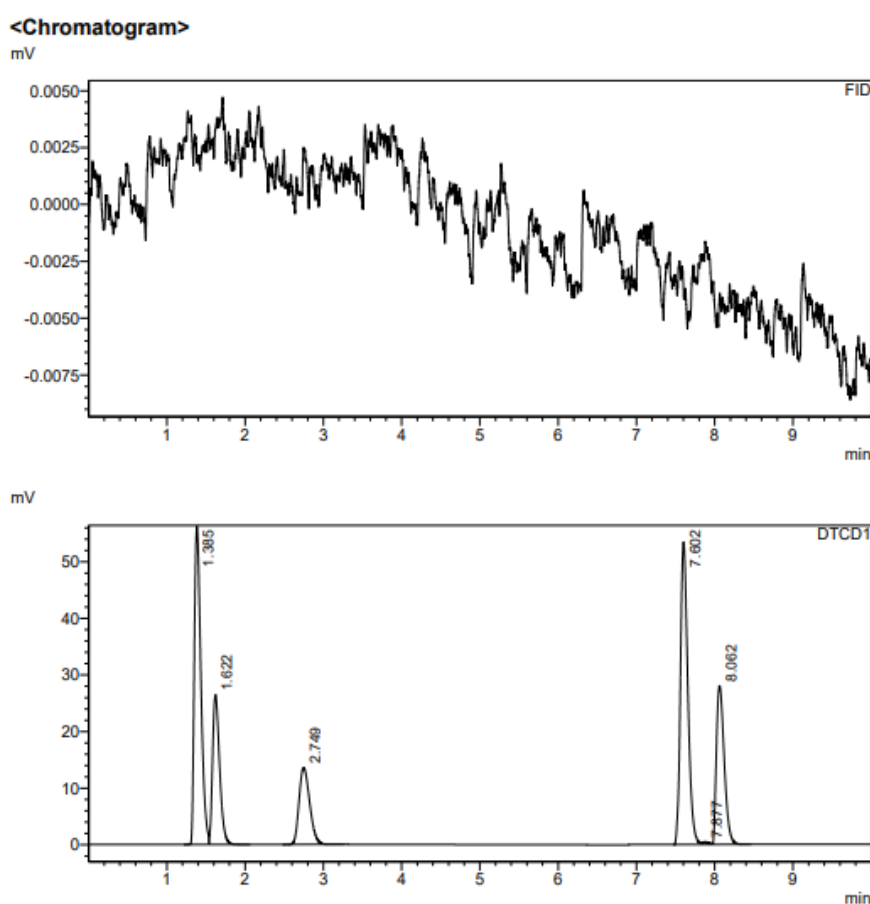


Figure 5. GC-FID reading after purification using woodchip biochar

Table 3. GC-FID reading after purification using woodchip biochar

Peak#	Ret. Time	Area	Height	Conc.	Unit	Mark	Name
1	1.385	328698	56128	0.000			
2	1.622	165679	26388	0.000		V	
3	2.749	128059	13548	0.000			
4	7.602	351952	53356	0.000	%	S	O2
5	7.877	1208	274	0.000	%	T	N2
6	8.062	194872	27994	0.000	%	V	CH4
Total		1170468	177687				

3.2. Biogas Purification

The biogas has been analysed through the GC-FID method. GC-FID is a detector typically used where the gaseous eluent is burnt in a flame, producing gas-phase ions of the analytes that are detected using an electrode (Cazenave-Gassiot *et al.*, 2008). Purification of biogas output using rice straw and wood chips biochar showed good results. When gas was extracted without biochar, CO₂ was detected. However, after using biochar for both rice straw and woodchip, CO₂ was purified, while CH₄, N₂ and O₂ remained. The quality of biogas is influenced by the purity of its CH₄. The calorific value of biogas depends on the purity of CH₄. This can be concluded by using rice straw biochar and wood chip biochar as adsorbents that can be used to purify the biogas and eliminate the CO₂. This enriched CH₄ in biogas can be collected for various applications, such as energy generation, heating, or fuel.

In the process of producing biogas, CO₂ and biomethane are separated using biochar, a type of charcoal made from organic materials. Gas adsorption may take place on a wide surface area of biochar because of its high porosity and surface area. It may also be made from a range of biomass sources and is an affordable, sustainable, and green material particularly for wood-derived biochar applications (Maroušek & Trakal, 2022). Once added, the biochar selectively absorbs CO₂ from the biogas stream, enabling biomethane to flow through. Then, using a variety of regeneration techniques, including thermal, chemical, or biological processes, the CO₂ may be readily extracted from the biochar (Cao *et al.*, 2022).

Since the biochar is porous, it serves as an adsorption medium for the biogas as it passes through the column loaded with it. A great deal of small holes and CO₂-affinity functional groups may be found on the surface of the biochar. Micropore size is also an important factor controlling CO₂ adsorption capacity (Rehman & Park, 2019). The biochar's surface attracts and clings to the CO₂ molecules in the biogas, drawing them out of the gas circulation. Owing to variations in molecule size and polarity, which allow CO₂ to be adsorbed more easily than CH₄, biochar is selective for CO₂ over CH₄. Since a substantial amount of the CO₂ has been adsorbed by the biochar, the gas stream that remains after the absorption column is now enriched in CH₄. It is possible to gather this enhanced methane for fuel, heating, or energy generation, among other uses (Cao *et al.*, 2022). This concludes that the biogas production is a sustainable energy source that contributes to more sustainable development.

3.3. Characterisation of Catalysis

Various methods can be applied to analyse biochar characteristics, including scanning electron microscopy (SEM), transmission electron microscopy (TEM), X-ray diffraction (XRD), Raman spectroscopy, X-ray photoelectron spectroscopy (XPS), Fourier-transform infrared adsorption spectroscopy (FTIR), and elemental analysis are commonly employed (Dong *et al.*, 2024; Vithanage *et al.*, 2015).

3.3.1. Micrograph study of biochar using scanning electron microscopy (SEM)

SEM may be used to anticipate the surface morphology before and after the adsorption process. Energy dispersive X-ray spectroscopy (EDX) and scanning electron microscopy are used to analyse the elemental composition of biochar. Moreover, the expansion of temperature during biochar test upgrades may result in a significant improvement in the pore characteristics of biochar. With increasing pyrolysis temperature, it is also possible that mineral segment crystallinity increases and highly desired sweet-smelling structures form in biochar, as eloquently stated by (Fellet *et al*2014).

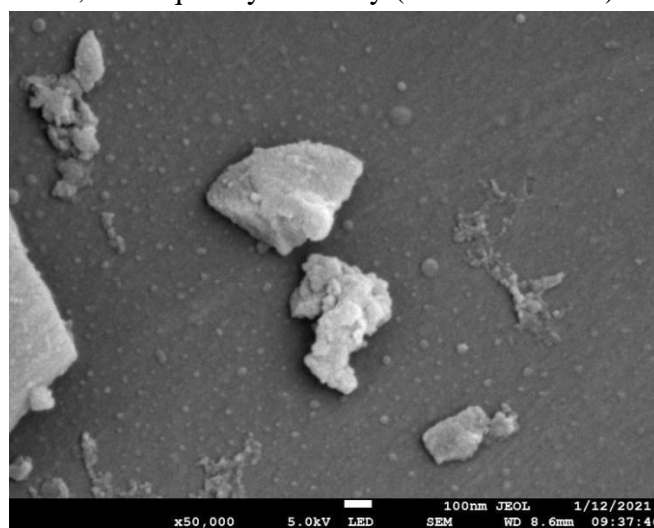


Figure 6. SEM for wood chips in 50000x zoom

3.3.2. Characteristic of the catalyst for wood chips

A plentiful and renewable resource, wood chips may be processed into a range of useful goods, including biofuels, bioproducts, and bioenergy. By quickening the reactions and increasing the yield and selectivity of the intended products, catalysts are crucial to the conversion of wood chips. The catalyst used in this study had a surface area of 693 m²/g, which was significantly higher than the surface area of bulk nickel (1.3 m²/g). This high surface area provides more sites for the adsorption and reaction of wood chip molecules. The

catalyst was also found to be porous, with a pore volume of $0.47 \text{ cm}^3/\text{g}$. This porosity allows the catalyst to access the interior of the wood chip particles, which improves the conversion rate (Song *et al.*, 2020).

The catalyst contained a high number of nickel metal sites, which are essential for the cleavage of C-C and C-O bonds in wood chip molecules. The catalyst also contained some acidic sites, which can catalyse the various reactions that are involved in wood chip conversion. The catalyst was found to be stable at temperatures up to $300 \text{ }^\circ\text{C}$ and at pressures up to 10 MPa. The catalyst was also able to be reused for multiple cycles without losing its activity (Song *et al.*, 2020).

3.3.3. Characteristic of catalyst for rice straw

In the process of converting rice straw, catalysts are important. For rice straw conversion, a highly active, selective, stable, long-lasting, and reasonably priced catalyst is suitable. Numerous novel catalysts for rice straw conversion have been developed because of recent research, which holds promise for enhancing the effectiveness and selectivity of these procedures. Rice-straw-derived lignin and modified rice straw composites have also been reported as effective adsorbent materials for metal ions, supporting the wider adsorption potential of rice-straw-based materials (Zhang *et al.*, 2017; B. Zhang, *et al.*, 2018; S, Zhang, *et al.*, 2018). The high pressures and temperatures that are frequently used in rice straw conversion procedures should not be able to harm the catalyst. It has the ability to catalyse the breakage of C-C and C-O bonds, which is necessary to transform rice straw into useful chemicals. As a result, the catalyst may interact with more molecules of rice straw, potentially increasing its activity and selectivity (Motlagh *et al.*, 2021).

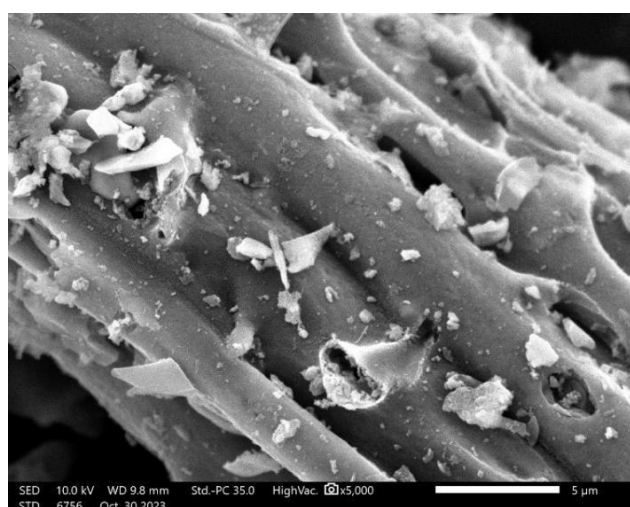


Figure 7. SEM for rice straw in $\times 5000$ zoom

4. Conclusions

Based on the results of the biogas purification using rice straws and wood chips biochar, using rice straw and wood chip biochar as absorbents can purify biogas and eliminate CO₂ after analysed with the GC-FID method, enriched CH₄ for sustainable energy for various applications of sustainable developments like energy generation, heating, and fuel (Cao *et al.*, 2022). Biochar, a type of organic charcoal, selectively absorbs CO₂ from the biogas stream, allowing CH₄ to flow through. Using regeneration techniques like thermal, chemical, or biological processes, CO₂ can be readily extracted from the biochar. The porous biochar surface attracts and clings to CO₂ molecules in the biogas, drawing them out of the gas circulation due to the rice straw and woodchip biochar characteristics as a catalyst (Goodman, 2020).

Due to variations in molecule size and polarity, biochar is selective for CO₂ over CH₄, resulting in a gas stream enriched in CH₄. The biochar's high porosity and surface area make it an affordable, sustainable, and green material for biogas production (Cao *et al.*, 2022). The process of producing biomethane is advantageous because it stops the emission of methane and other hazardous gases into the atmosphere. It also lessens the need for fossil fuels, which further lowers greenhouse gas emissions. (Boraah *et al.*, 2022). Furthermore, the generation of biomethane benefits non-energy sectors. They are produced from various organic residue kinds, converting waste into an important resource that supports economic growth (Amin, 2022).

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