Original Research Article

Characterisation of Coconut Shell, Coconut Shell Biochar, Coconut Coir, and Coconut Shell Activated Carbon as Potential Adsorbent Materials: A Comparative Study

Abstract:

Industrial development and population growth increase water and air contamination. As such, adsorbents are used to eliminate or reduce pollutants from water and gas systems to protect water quality and gases. Biomass is a low-cost adsorbent that has gained considerable attention. This research aims to produce, investigate, and characterize coconut shell biochar (CSB) and compare it with the literature. Moreover, analytical techniques, such as scanning electron microscope (SEM) and Fourier transform infrared spectroscopy (FTIR), were used to characterize the coconut shell biochar. The proximate analysis of coconut shell biochar was 65.10% fixed carbon, 11.4% moisture, 20% volatile matter, and 3.5% ash. This research was then compared with previously published results of coconut shell (CS), coconut coir (CC), and coconut shell activated carbon (AC). Based on the findings of this work, CSB is considered a suitable raw material, which has excellent potential as an adsorbent for the adsorption of toxic gases.

Keywords: *Biomass, coconut shell, coconut shell biochar, coconut coir, coconut shell activated carbon.*

1- Introduction

Biomass is widely available globally; nevertheless, the technologies relevant to biomass conversion as a useful energy source are yet to be established. While most of them are accessible anywhere globally, it is widely spread in its sources and is difficult to collect (Popp et al., 2021). Biomass is primarily produced from the forestry or agriculture sector, municipal solids waste (MSW), food processing waste, and animal manure (Bedia et al., 2018). There are different types of biomass which are utilized for adsorbent production worldwide(Akpasi & Isa, 2022). These wastes are accessible, cost-effective, naturally occurring, and sustainable. An evaluation into the application of agricultural waste (agro-waste) has been used to remove heavy metals from aqueous solutions and increase toxic gas adsorption (Thompson, Ndukwe; & Asadu 2020).

Biomass resources are all forms of organic materials, including plant matter, both living and in waste form, as well as animal matter and their waste products (Bedia Jorge et al., 2018). In contrast to other fruits, coconut (*Cocos nucifera* L.) is a year-round agricultural product. The Philippines, Indonesia, India, Malaysia, Hawaii, Africa, South America, the Pacific Islands, and other tropical climates produce the majority of the world's coconuts (Kabir Ahmad et al., 2021). Malaysia has used approximately 142,000 hectares of land for coconut plantation, and a vast amount of coconut biomass is generated annually (Hayatu; Nasri; & Zain 2017). Over the past decades, rigorous attention has been given to the viability of utilizing lignocellulosic biomass as a source of carbon adsorbent preparation.

Increased coconut water and green coconut fruit pulp consumption have subsequently increased the production of CS, which tends to be converted into waste in some areas, creating unacceptable social, economic, and environmental impacts (Biggs et al., 2015). According to the literature, CS has the potential for different usage in the form of powder, coir for the production of semi-crystalline magnetite nanoparticles (Sebastian; Nangia; & Prasad 2018), Ag ion sorption (Staroń et al., 2017), thermal insulation (Sistema et al., 2015), panels (Ayrilmis et al., 2011), blankets for soil protections, and aggregation of cement composites(Tomar et al., 2021). The CS is very widely used in industrial applications as fertilizer (Wasis& Ghaida; & Winata, 2019), aggregates in concrete (Leman et al., 2016), and membrane separator (Neethu et al., 2018), primarily due to its wide accessibility in many world regions (Ripa et al., 2017).

Many by-products of agricultural waste are used instead of trees to replace wood as the carbon source. It is possible to develop activated carbon from many sources, such as cherry stones, macadamia nutshells, and palm husks (Saleem et al., 2019). CSB is a high-sorbent carbonaceous biochar substance generated from the incomplete burning of biomass from waste. Furthermore, CSB is widely used as a cost-effective adsorbent in handling wastewater and removing toxic gases(Packialakshmi et al., 2021). Several methods have been applied to improve heavy metal soil adsorption by combining it with CSB, such as AC adsorption, membrane operation, and carbon nanotube (Fiyadh et al., 2019).

Throughout the 20th century, the rapid development of industrial society promotes the increasing production and usage of AC, particularly in the second half of the last century, because of stricter environmental restrictions on water resources, clean gas application, air quality control, energy storage/conversion, and economic recovery of valued chemicals (Grycova et al., 2018). According to the literature, AC is a porous compound with a large surface area and a high potential for adsorption to eliminate toxins, such as dyes, heavy metals, chemicals and gases, and wastewater. AC has various applications in numerous industrial sectors, such as fruit, pharmaceuticals, chemicals, petroleum, mining, and, in particular, drinking water treatment(Alves et al., 2021).

CC is the coconut husk coir, a strong, coarse, yet durable coir. CC is a sustainable material that is non-polluting and relatively waterproof, with resistance to saltwater disruption and microbial degradation. CC is widely used as an adsorbent in industrial wastewater treatment. It contains pigment, heavy metals, and organic and inorganic contaminants such as methylene blue (MB)(Rudi et al., 2020).

This article aims to produce biochar using a furnace and compare the properties of coconut shell biochar with CS, CC, and AC for their potential use as adsorbent materials.

2- Experiment

2.1 Materials

The commercialized CS used in this research was obtained from Kuala Krai, Kelantan, Malaysia. The raw CS was dried in an oven based on ASTM standards for 24 h at 105 ± 5 °C, and the CS was crushed until it had a size ranging between 1–10 mm.

2.2 Methods

2.2.1 Biochar production

The CS was crushed after drying using mortar and pestle and passed through 80 mesh serves. The initial substance was subsequently moved to a furnace and subjected to pyrolysis in an oxygen-restricted environment within a muffle furnace without using nitrogen or any other inert gas. Residence periods of 120 minutes and pyrolysis temperatures of 600 °C. Fig 1 illustrates the biochar production procedure.

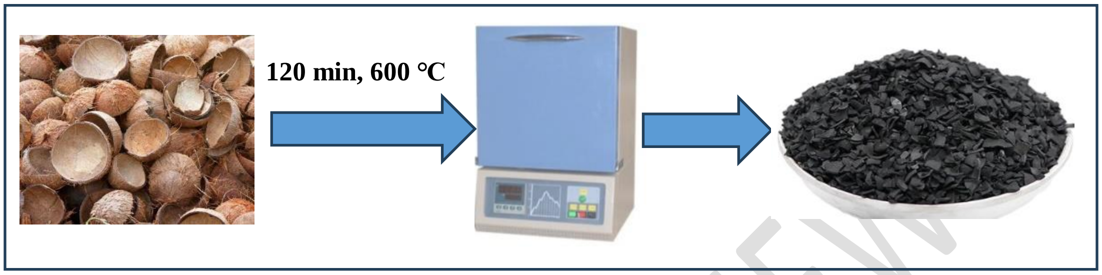


Fig. 1. Biochar production procedure

2.2.2 Proximate Analysis

The amount of moisture, volatile matter, fixed carbon, and ash analyses was determined using a Thermobalance TGA/SDRA51e. The biomass sample containing 10–15 mg was weighed and placed inside the analyzer in a cylindrical ceramic furnace. At the beginning of the operation, the heating rate was set at 10°C/min, and nitrogen gas was injected. When the mass loss plateau was established at 600°C to 950°C, the gas was switched from nitrogen to air to determine the ash and fixed bed carbon content. At the end of the analysis, the temperature reached 1,300°C.

2.2.3 Fourier Transfer Infrared Spectroscopy (FTIR)

FTIR is an essential analytical technique for detecting various functional groups in biochar. Regardless of the structure of the remainder of the molecule, when infrared light interacts with the biochar, the chemical bonds stretch, contract, and absorb infrared radiation in a particular wavelength range. The FTIR spectrometer used in this experiment is the Perkin Elmer Spectrum GX FTIR spectrometer, which has a wavelength range of 4,000– 400 cm^{-1}. AST|M D6348-12 standard was used to determine the substance compositions.

2.2.4 Scanning Electron Microscope (SEM)

A scanning electron microscope (SEM) was used to investigate the morphologies of the materials. The materials are coated with gold to increase their electric conductivity before being scanned with electron beams at 10–15 kV acceleration power to achieve 1,000–

3000 times resolution. The process was followed by a standard test described in detail by the American Society for Testing and Materials Specification, ASTM E766 – 14.

3- Results and discussion

4.1 Proximate analysis

The findings of this research CSB were compared with the results of CS, AC, and CC, all of which have been previously reported. Table 1 demonstrates the proximate analysis of CSB in this work and previous studies.

Table. 1. Proximate analysis of CSB of this work and that of previous studies

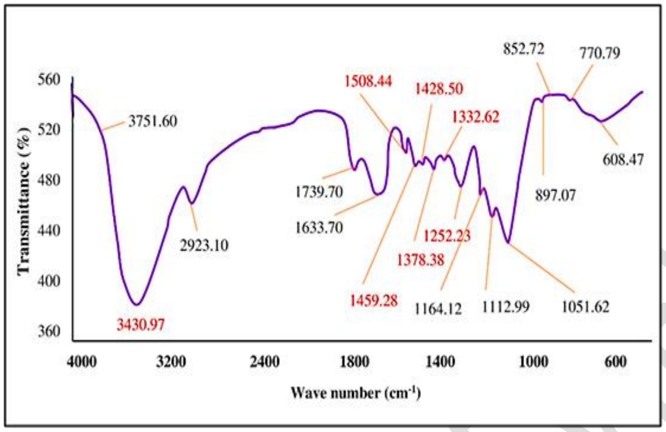
Properties (%)	Fixed Carbon	Moisture	Volatile matter	Ash	Reference
Coconut shell	12.04	7.72	79.91	0.23	(Mohd Iqbaldin et al., 2013)
Coconut shell biochar	65.10	11.4	20	3.5	This study
Coconut shell-activated carbon	69.49	-	28.46	2.05	(Mohd Iqbaldin et al., 2013)
Coconut shell coir	11.20	19.45	65.2	4.15	(Ángel Hidalgo-Salazar et al., 2020)

The above analysis shows that the has a higher fixed carbon of 69.49% compared with CS at 21.38%, CC at 11.2%, and comparable with CSB at 65.10%, which resulted in better adsorbent for adsorption purposes (Das et al., 2015). The analysis shows that CC has a higher moisture of 19.45% compared with CSB at 11.4%, CS, and AC. Results show that AC has 28.46% and CSB 20 %, the lowest volatile matter and ash content compared with CC 65.2 % and CS 79.91 %. AC and CS possess a high amount of fixed carbon and a low moisture level. Due to its higher moisture and lower fixed carbon content, CC is more suitable for soil amendment and erosion control than for carbonization. Biochar, derived from the pyrolysis of CS, possesses a low moisture and volatile matter content while exhibiting a high fixed carbon content. This characteristic makes it highly effective in promoting adsorbent, soil fertility, and sequestering carbon. AC made from CS has a very high amount of fixed carbon and very little volatile matter. This gives it fantastic adsorption abilities for cleaning and filtering. The high content of fixed carbon in CSB makes it a good starting material for preparing adsorbents and energy generation(Kabir Ahmad et al., 2022).

4.2 Fourier Transfer Infrared Spectroscopy (FTIR)

Fig 2 shows the FTIR spectroscopy of (a) CS, (b) CSB, (c) CC, and (d) AC, which consists of aromatic, carboxyl, ether, Esther, and alcohol groups.

A



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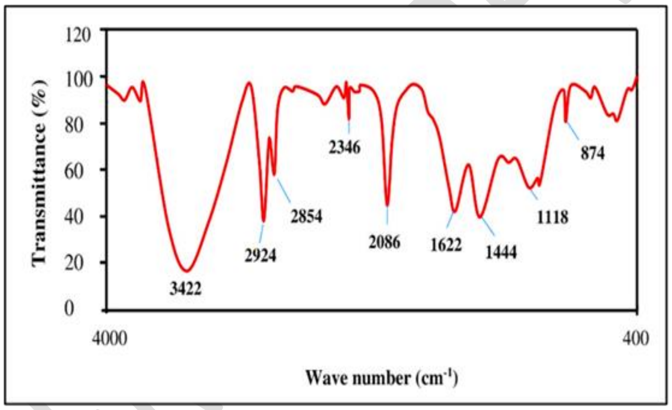

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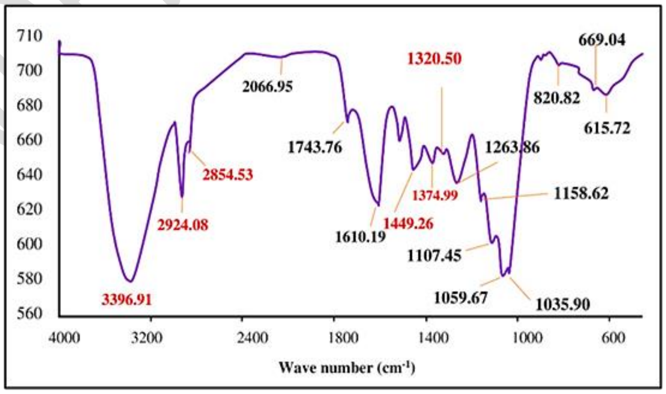

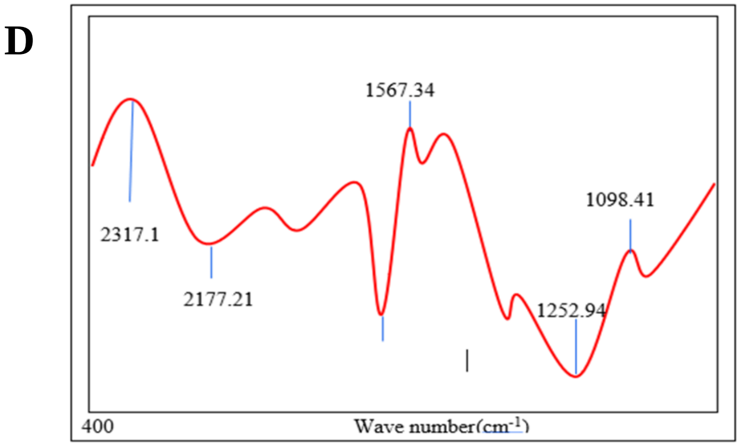

Fig. 2. FTIR spectra of (a) CS; (b) CSB; (c) CC; and (d) AC (Lazim et al., 2015; Zhang et al., 2018; & Das et al., 2015).

FTIR spectroscopy was used to analyze the samples and identify the specific functional groups on the surface area. Agricultural waste often has similar functional groups that can partially bind pollutants. These groups include hydroxyl, carboxyl, and aromatic groups. Band shifting around the broad peak at 3751.60- 3396.91 cm^{-1} has indicated the potential presence of hydroxyl groups. The intensity of the peak decreased for all of the biochars following pyrolysis. With the increase in pyrolysis temperatures, there was a gradual decrease in the intensity of the hydroxyl (–OH) functional group. The presence of the condensed C structures was indicated (Aninda Dhar et al., 2022). The peaks observed at 2924.08 and 2854.53 cm^{-1} result from the vibrational movements caused by the stretching of C-H bonds in the CH, CH2, and CH3 groups. The peak corresponds to stretching C–H bonds in alkyl groups. The absence of a weak peak was seen in all the spectra of the biochars(Rafiq et al., 2016). The absorption bands appear at approximately 2346- 2066.95cm^{-1}, indicating the presence of C=C bonds in aromatic rings. The bands around 1743.76- 1252.63 cm^{-1} showed the presence of carboxyl groups. The peaks observed at 1107.45- 1035.90 cm^{-1} have been attributed to the stretching and bending of Si–O bonds, indicating the presence of silica. The bounds between 820.42-615.72cm^{-1} indicate the aromatic compounds C-H. The intensity increased with higher pyrolysis temperatures. The hydrolyzed biochars at 450–600 °C exhibited an apparent aromatic bend of the C–H phenyl ring at around 875 cm^{-1}(Peng et al., 2011).

4.3 Morphological observation by scanning electron microscope (SEM)

Fig 3 shows the SEM of CS, CSB, CC, and AC with a magnification of 3000x. Therefore, the initial study involved applying a platinum coating to the samples for 1 minute. This step was necessary to facilitate ion exchange in the samples classified as nonconductive materials. The coating process was carried out under a pressure of 2 MPa to eliminate any discharge ions and ensure that the analysis remains undisturbed. The SEM images were used to examine the porosity of the samples by analyzing surface morphological differences and structural modifications.

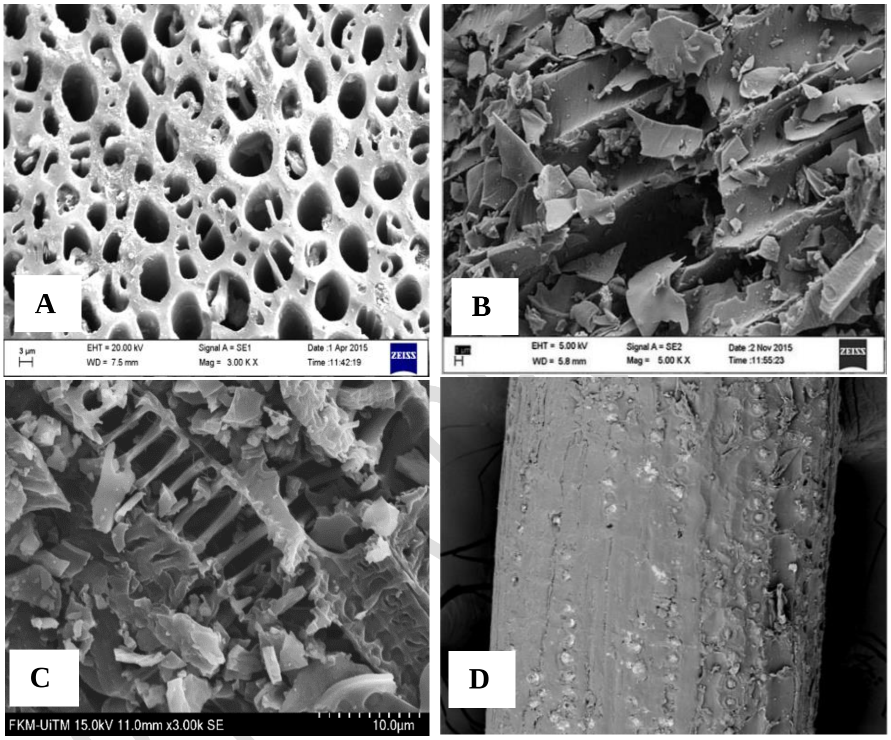

Fig. 3. SEM of (a) AC, (b) CS, (c) CSB, and (d) CC (Suman & Gautam, 2017, Das et al., 2015; Stapper et al., 2021).

The process of carbonization and activation eliminates volatile substances, resulting in the formation of a solid mass of carbon. This process also expands the pore networks found in the activated carbon sample. Additionally, the AC was chemically activated, leading to an increase in surface area and pores (Das et al., 2015). The CS is an organic structure with a high concentration of carbon and oxygen. It exhibits a rigid composition and a highly uneven surface. This irregular surface texture contributes to its distinctive structural characteristics(Suman & Gautam, 2017). The CC was found to be the SEM analysis of the coconut coir, which revealed that there were no visible signs of surface layer removal or any damage to the fiber cells. The structural integrity of the coir fibers remained intact, with no observable disruption to the outer surface or the underlying cellular structure(Stapper et al., 2021). The solid biochar had a rigid, irregular surface with a few pores. The CSB contained a sheet surface and an increased surface area. The parameters such as temperature and method were found to be dominant.

Conclusion

CSB is a highly versatile material with high adsorption capacity, and this capability, combined with its low cost of production and environmental sustainability, makes CSB a highly attractive candidate for the adsorbent. The proximate analysis obtained for the CSB in this study showed that the coconut shell biochar had high values of fixed carbon of 65.10% and lower ash content of 3.5% compared with CS at 21.38% and 0.8% and CC at 11.20% and 4.15%, respectively. Moreover, CSB and AC with a sheet surface and increased surface area show their possible uses in adsorption.

The most important observation was the difference in the number of functional groups. FTIR analysis shows that the coconut shell has more functional groups than CSB and AC. Based on the FTIR results, temperature has a direct control efficacy on the functional groups.

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