

Sustainable Materials and Technology

Showkat Ahmad Bhawani
Aamir Hussain Bhat
Rafeah Wahid
Zainab Ngaini *Editors*



Biochar

A Sustainable Approach

 Springer

Sustainable Materials and Technology

Series Editors

Mohammad Jawaid, Chemical and Petroleum Engineering, United Arab Emirates University, Al Ain, United Arab Emirates

Anish Khan, Centre of Excellence for Advanced Materials, King Abdulaziz University, Jeddah, Saudi Arabia

Sustainable Materials and Technology (SMT) book series publishes research monographs (both edited and authored volumes) showcasing the latest developments in the field and comprehensively covering topics such as:

- Recycling of waste into useful material and their energy applications
- Catalytic action of Nano oxides for efficient carbon reforming process
- Sustainable technologies for plastic transformation
- Bifunctional nanoparticles for sustainable water splitting applications
- Sustainable dyeing and printing
- New materials from waste
- Sustainable Manure Management and Technology: Potentials, Uses and limitations
- Sustainable Mechanical Engineering Approach
- Sustainable biochemistry for the improvement of health
- Sustainable development of Mechanical recycling of automotive components
- Sustainable-waste recycling and conversion in useful materials for different applications
- Sustainable development of inexpensive Nano-photo catalysts
- Sustainable development of recycling of discarded lithium ion batteries
- Modern sustainable cement and concrete
- Sustainable adsorbent for hazardous removal
- Sustainable superior electromagnetic shielding materials
- Excellent sustainable nanostructured materials for energy storage device
- Sustainable development of heavy metal detoxification from water
- Carbon dioxide utilization for sustainable energy
- Sustainable development in green syntheses of materials
- Environment friendly and sustainable cloth for garments application
- Sustainable design and application of eco-materials
- Nanoparticles for sustainable environment applications
- Sustainable remediation of industrial contaminated water towards potential industrial applications
- Biomaterials for sustainable bioremediations

Showkat Ahmad Bhawani · Aamir Hussain Bhat ·
Rafeah Wahi · Zainab Ngaini
Editors

Biochar

A Sustainable Approach

 Springer

Editors

Showkat Ahmad Bhawani
Faculty of Resource Science
and Technology
Universiti Malaysia Sarawak
Kota Samarahan, Malaysia

Rafeah Wahid
Faculty of Resource Science
and Technology
Universiti Malaysia Sarawak
Kota Samarahan, Malaysia

Aamir Hussain Bhat
Applied Chemistry Section
College of Applied Sciences and Pharmacy
University of Technology and Applied
Sciences
Muscat, Oman

Zainab Ngaini
Faculty of Resource Science
and Technology
Universiti Malaysia Sarawak
Kota Samarahan, Malaysia

ISSN 2731-0426

ISSN 2731-0434 (electronic)

Sustainable Materials and Technology

ISBN 978-981-97-4251-6

ISBN 978-981-97-4252-3 (eBook)

<https://doi.org/10.1007/978-981-97-4252-3>

© The Editor(s) (if applicable) and The Author(s), under exclusive license to Springer Nature Singapore Pte Ltd. 2024

This work is subject to copyright. All rights are solely and exclusively licensed by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, expressed or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.

The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

If disposing of this product, please recycle the paper.

Contents

Production, Characterization, and Properties of Biochar	1
Zainab Ngaini, Nur Aqilah Makshut, Rafeah Wahi, and Showkat Ahmad Bawani	
Modifications of Surface Properties of Biochar by Different Treatment Methods	19
Rafeah Wahi, Muhammad Imran-Shaukat, Zainab Ngaini, and Nur Fakhirah Qurratu'ain Zuhaidi	
Recent Advances in Biochar as Low Cost Biosorbent for Adsorption of Dyes and Heavy Metals	37
A. H. Bhat, Imran Khan, Showkat Ahamd Bhawani, M. K. Abdul Rahim, Naveed Ahmed, and Laila Khamis AlMaqbali	
Designed Biochar for Heavy Metals Removal from Wastewater	53
Azreen Farhana Hasnain and Zainab Ngaini	
Nano-biochar Composites for Decontamination of Wastewater	65
Basma Al-Najar, Alia Mustafa, Khadija Al-Yaqoob, and Hanan Albuflasa	
Biochar for Electrochemical Energy Storage	93
Naveed Qasim Abro, Bakhtiar Ali Samejo, and Najma Memon	
Biochar in Redox-Mediated Reactions for the Removal of Organic Pollutants from Water Resources	151
Khalid Umar, Saima Khan Afridi, Zayed Abdullah Salem Al-Ghurabi, Tabassum Parveen, Rohana Adnan, and Mohd Jameel	
Biochar-Based Catalysts for the Production of Chemical and Energy	169
Utsav Garg and Yasser Azim	
Biochar-Based Catalysts for Pollution Control	191
Saba Farooq and Zainab Ngaini	

Biochar for Remediation of Contaminated Soil 207
Parveen Begum, Kaizar Hossain, Akil Ahmad,
and Siti Hamidah Mohd Setapar

Biochar as a Carrier for Agrochemicals 221
Wan Roslina Wan Yusof, Sumiyyah Sabar, Enis Nadia Md Yusof,
and Nur Shazwani Abdul Mubarak

Production, Characterization, and Properties of Biochar



Zainab Ngaini, Nur Aqilah Makshut, Rafeah Wahi,
and Showkat Ahmad Bawani

Abstract Biochar-based research has been widely studied due to its superb physio-chemical properties and versatile applications. Numerous carbonization techniques of biomass have been introduced to form unique properties of biochars through thermochemical decomposition from the conventional to the latest technology (i.e., muffle, microwave, and tube pyrolysis) with higher porosity. During pyrolysis, the biowaste materials steadily transformed themselves into porous structured spherical shape particles with smaller particle sizes and higher surface area distributions. Nanostructure biochar showed a distinctive and ideal material for transdisciplinary usage due to its outstanding chemical, physical, and biological elements. Biochar has adaptable applications as fertilizer for soil amendment and also as an adsorbent for the removal of organic pollutants, dyes, and heavy metals. This chapter also describes the advancement in technology for the bioconversion of agricultural wastes into value-added products, which provides an eco-friendly alternative for a sustainable waste management system and benefits mankind.

Keywords Adsorption · Biomass · Lignocellulosic · Pyrolysis · Porosity

1 Introduction

Biochar is a black composite discovered in 3000—500 years BP in the Amazonian basin [1]. The Amazonian Black Earth or *Terra Preta do Indio* has intrigued the interests of researchers to discover the versatility of biochar due to the significant fertility of the soils compared to other tropical soils [2]. Naturally, biochar is found in the soil as a result of wildfire and the decomposition of organic matter after a long period [3]. In other words, biochar is a carbon-rich pyrogenous material which

Z. Ngaini (✉) · N. A. Makshut · R. Wahi · S. A. Bawani
Faculty of Resource Science and Technology, Universiti Malaysia Sarawak, 94300 Kota
Samarahan, Sarawak, Malaysia
e-mail: nzainab@unimas.my

N. A. Makshut
e-mail: 24010218@siswa.unimas.my

© The Author(s), under exclusive license to Springer Nature Singapore Pte Ltd. 2024
S. A. Bhawani et al. (eds.), *Biochar*, Sustainable Materials and Technology,
https://doi.org/10.1007/978-981-97-4252-3_1

commonly produced from the thermal degradation of organic materials, such as biomass and agricultural wastes under a limited oxygen supply [4].

Biochar is a versatile material that is widely used for the treatment of contaminated soil, catalysis, energy storage, and many others [5]. The wide application of biochar has been reported in agriculture as a soil amendment. The addition of biochar to soil can enhance its pH, ability to store moisture, cation-exchange capacity, microbial flora [6], as well as concentrations of phosphorus and total nitrogen. A wide range of biomass is used to produce biochar, such as seaweed (*Gelidiella acerosa*) [7], Foxtail palm trunk (*Wodyetia bifurcata*) [8], coconut shell [9], and Bermuda grass [10]. The carbonization of biomass is producing biochar with the desired properties for various applications, such as an adsorbent for water-soluble pollutants in the wastewater as well as gaseous pollutants in the air [11].

Nowadays, biochar from agricultural resources is commonly used as the precursor to produce activated carbon by introducing acid or basic activation with activators, such as zinc chloride (ZnCl_2), phosphoric acid (H_3PO_4), sodium hydroxide (NaOH), and potassium hydroxide (KOH) followed by physical treatment (carbonization process) to produce activated carbon. The formation of activated carbon from these sources aids in economic management due to its low-cost production, easily produced, environmentally friendly, and versatile usage [12].

2 Production of Biochar

2.1 Biochar Precursors

The precursors for biochar production are commonly obtained from agricultural wastes or biomass. Biomass is a biological and non-biological solid product generated from living organisms that have no known values and applications, thus classified as waste materials [13]. Biomass is considered a sustainable renewable energy feedstock and an ideal source for the production of biochar [14]. Plant-based agricultures, such as sago bark [15], sago pith [16], corn cob [17], and Bermuda grass [10], have been reported as biomass sources due to abundance availability and highly composed of structural components (lignocellulosic materials) and non-structural components (extracts), such as starch, tannins, and metal oxides.

The lignocellulosic materials, such as cellulose, hemicellulose, and lignin, act as the building structure of plant-based biomass. The biggest component of lignocellulosic biomass, accounting for 38–50% of its weight, is cellulose while hemicellulose is the second largest fraction that contributes 20–40% by weight of biomass. Hemicellulose is responsible for the hygroscopicity of the biomass. Lignin is the amorphous compound associated with the sturdiness of biomass and contributes 15–25% of the biomass fractions [18]. Other trace materials or the extracts contribute the least percentage by weight of biomass and are not related to the structure built of biomass.

2.2 Carbonization Methods of Biomass

There are many methods reported on the carbonization of biomass to produce biochar namely hydrothermal treatment [19], steam gasification [20], torrefaction [21], and pyrolysis [22]. The hydrothermal treatment utilizes water as the medium of temperature regulatory between 120 and 350 °C [19]. This is a common process for the preparation of biochar which involves a simultaneous reaction of hydrolysis, decarboxylation, condensation, and dehydration that breaks the lignocellulosic structure of biomass [23] (Fig. 1). The biochar produced from hydrothermal treatment emits high carbon fractions, reduced volatile matter, and high calorific values that make it suitable for solid fuel [23, 24].

Another method reported in the preparation of biochar is via steam gasification [20] and the torrefaction process [21, 25] (Fig. 2). Steam gasification requires a high temperature to heat the gasifier (800–870 °C) and produced high-density biochar with numerous pore structures and high biochar yield [26]. The carbonization of biomass requires two connected fluidized bed reactors for gasification and heat generation during gasification treatment [20]. The torrefaction process is another process to produce biochar. It is a mild pyrolysis method that is similar to conventional pyrolysis with a lower temperature and pressure. The torrefaction method of biomass has been reported to have high energy density and low oxygen content which makes it a good feedstock for the production of activated carbon [27].

Pyrolysis is another carbonization method of biomass to produce biochar. It is the most reported method for thermal degradation of biomass [22]. Biomass pyrolysis is extensively studied employing different carbonization conditions and reactors. It is a thermal degradation process of lignocellulosic materials under high temperature and oxygen-starved atmosphere [28].

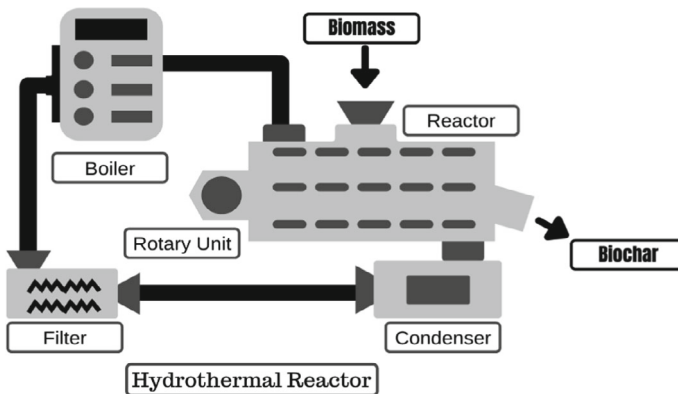


Fig. 1 Preparation of biochar using hydrothermal reactor