ScienceDirect

Diamond and Related Materials

Volume 143, March 2024, 110912

The effect of microwave and muffle furnace-assisted heating on the surface characteristics of teff husk activated carbons: Thermodynamic, isotherm, and kinetics study of Pb removal

Khalid Siraj [a b], James Simon Aballa [b], Mohammed Danish [c d], Tanweer Ahmad [e], Mohammad Mansoob Khan [f], Shahnaz Majeed [g], Birtukan Adane [b]

Show more

https://doi.org/10.1016/j.diamond.2024.110912

Get rights and content

Highlights

- The BET surface area of MW-THAC and MF-THAC were 9.81 and 327 m^2/g.
- At 25 and 45 °C temperatures, the adsorption capacity of MW-THAC against Pb^{2+} was 17 and 20 mg/g.
- At 25 and 45 °C temperatures, the adsorption capacity of MF-THAC against Pb^{2+} was 25 and 26 mg/g.
- The Pb^{2+} removal followed the Langmuir isotherm and PFO kinetic model for MW-THAC.
- The Pb^{2+} removal followed the Freundlich isotherm and PSO kinetic model for MF-THAC.

Abstract

This study explored the fabrication of activated carbon from teff husk biomass using microwave and muffle-furnace-assisted heating and observed its effect on surface characteristics and the thermodynamics, isotherm, and kinetics of Pb^{2+} ions removal. Chemical activation of the teff husk was carried out using $ZnCl_2$ as an activating agent. The microwave-assisted activated carbons (MW-THAC) and muffle furnace-assisted activated carbon (MF-THAC) were characterized for surface area, pHzpc, functional groups, thermal stability, phase composition, surface morphology, and surface-elemental compositions. The surface area of MW-THAC and MF-THAC was found to be 9.81 m^2/g and 327.54 m^2/g, respectively. Thermodynamic parameters indicated that the interaction with MW-THAC and MF-THAC was spontaneous and endothermic. The maximum Pb adsorption capacities of MW-THAC and MF-THAC calculated using the Langmuir model at 45 °C were found to be 20.45 mg/g and 26.04 mg/g, respectively. Pb^{2+} removal through MW-THAC followed the Langmuir isotherm and the pseudo-first order kinetic model. However, the Freundlich isotherm and pseudo-second order kinetic models best describe Pb^{2+} adsorption onto the MF-THAC surface. The desorption study shows that 80.6% and 78.7% of Pb^{2+} ions can be recovered from the surfaces of the MW-THAC and MF-THAC adsorbents. This study confirms that activated carbon derived from teff husk could be a potential candidate for the adsorption and recovery of Pb^{2+} ions.

Graphical abstract

Download: Download high-res image (115KB)

Download: Download full-size image

Introduction

After the third industrial revolution, the burgeoning of different-scale industries around the big and small cities caused a nuisance of pollution. In view of this, ecological protection to maintain natural habitat seems daunting. Environmental contaminants cause many species of animals and plants to disappear; now human life is also in danger. The pollutants ingested into the human body through water and food cause many life-threatening diseases, such as cancer, kidney failure, and liver-related diseases. The economic growth and people's demand for nonconventional products due to changes in lifestyle contribute significantly to the nonsustainable growth of the industries. Abounding parts of the product manufacturing industries consume high-concentration chemicals; after processing, the residual chemicals are drained into the pond or water channel near the

location of the industry. The long-time practice of throwing chemically loaded effluent into nearby drainage or ponds percolates it into groundwater; subsequently, it starts showing its effect on the growth of nearby plants and animals. Among heavy metals, lead is one of the persistent contaminants that deteriorates the natural ecological balance in the habitat. The source of industries that generate lead metal ions is many; among them, a few front-line industries are vehicle manufacturers (brake pads, tyres, and lubricant additives), agricultural insecticides (lead arsenate), ceramic products, paint, electroplating, and battery industries [1]. The growth of these industries as a result of an increasing population has prompted the release of lead ions in the water bodies. From a contaminated environment (soil, air, and water), the lead ions enter the human body through water, air, and food (vegetables and grains grown in polluted soil and nourished with contaminated water), accumulating in the bones [2]. The lead accumulation in the human body causes carcinogenesis, mutagenesis, and teratogenesis. Instant ingestion of lead ions above 40μg/L concentration can have toxic effects on human sperm.

Lead (Pb) ions in drinking or irrigation water are toxic even in small concentrations and pose a serious threat to the survival of humans, animals, and plants. Pb ions are extremely persistent in nature and neither biodegradable nor thermally decomposable to environmentally benign molecules. Thus, their aggregation easily attains toxic levels [3]. Children exposed to high concentrations of Pb^{2+} ions may become mentally disabled, fall into a coma, and even die of lead poisoning. An alarming level of Pb ion concentration in the blood of children is 10μg/L and for adults 25μg/L. The joint technical expert committee of the Food and Agriculture Organization (FAO) and the World Health Organization (WHO) on food additives established that the weekly permissible limit of lead concentration in consumable foods is 0.025mg/kg body weight [2].

Sustainable and cost-effective materials can be utilized to mitigate such toxic metal ions from contaminated water. In the recent past, many biomass and biomass wastes were converted into effective adsorbents such as wood biomass [4], date stone [5], palm tree waste [6], banana plant waste [7], orange peel [8], mangosteen peel waste [9], cassava stem [10], coconut shell [11] and bamboo [12]. Raw biomass can be used directly or modified with surfactants before using it as an adsorbent, but its adsorption efficiency is limited [13]. Therefore, converting biomass to activated carbon gives the additional advantage of managing a large volume of biomass in small and condensed carbon-rich adsorbents with a large surface area [14,15].

Teff has been widely grown in East Africa for thousands of years. Ethiopia has teff husk cultivation land of nearly 2.59×10^{6}ha, which is 28% of the total area of cereals cultivated in the country. The average production of teff grain is 1228kg/ha under extreme conditions of soil nutrient limitation, drought, and waterlogging [16]. The teff straw waste was generated nearly three times that of the teff cereal grain produced from the teff plant. Managing such a large volume of teff straw waste is a challenging task. Therefore, the production of activated carbon from the teff straw waste reduces the volume of the waste and provides a very useful material with an extended surface area. So far, only four studies have reported on straw-based teff adsorbents [[17], [18], [19], [20]]; therefore, this biomass must be explored to prepare adsorbents using different preparation methods and tested against various pollutants. Tadesse et al. [17] used raw teff straw as an adsorbent against the removal from wastewater, and Desta et al. [18] prepared char from teff straw at 400°C and used it for the treatment of textile effluent for the removal of metal ions. Adane and Dessie [19] prepared

chemically activated carbon from teff straw using sulfuric acid to test its applicability against hexavalent chromium ions. Wassie et al. [20] prepared the adsorbent from teff straw by washing it with water and drying and milling it to break it in the 0.1–0.6mm particle size range. The prepared teff straw powder was scavenged Cr(VI) from the water solution. Microwave heating was used for the chemical activation of agricultural waste, and the prepared adsorbent was applied to scavenge methylene blue dye [21]. Until now, no study has reported a comparative study to remove Pb^{2+} ions from lead-contaminated water using zinc chloride-treated teff husk-activated carbon prepared by microwave and muffle furnace heating methods.

This study aims to transform the teff husk into activated carbon through $ZnCl_2$ treatment and activated through microwave and muffle furnace-assisted heating methods. The activated carbon obtained through these two heating methods was compared by surface area, pHzpc, surface functional groups, thermal stability, phase composition, surface morphology, surface elemental compositions, and Pb^{2+} adsorption efficiency under different independent variables (adsorbent dosage, contact time, solution pH, initial concentration of Pb^{2+} ions and solution temperature). Thermodynamics, isotherm, and kinetics of Pb^{2+} adsorption were also compared. The recyclability of the prepared adsorbents was also evaluated through desorption experiments.

Section snippets

Raw teff husk preparation

The raw teff husk was randomly collected from different teff grain processing mills located in the Jimma area, Ethiopia. The teff husk was sent to the analytical and physical chemistry research laboratory at Jimma University, Jimma, Ethiopia. After collection, the teff husk sample was washed repeatedly with supply water and subsequently with distilled water. The wet teff husk was open dried under sunlight for 4days to reduce the water absorbed in the husk; it was further dried in a hot air …

Effect of time, temperature, and microwave power on activated carbon formation

In a muffle furnace, heating from the source was transmitted to the teff husk surface through the convection, conduction, and radiation modes, and it can be monitored through the control panel. The heat wave migrated from the outer surface to the bulk of raw materials and developed a temperature gradient. Therefore, uniform shape, smaller particles, and dry biomass are advantageous for avoiding uneven heating. The grounded teff husk particle size <250μm with an almost uniform shape was used in …

Conclusion

This study successfully transformed the teff husk into activated carbon using microwave and muffle furnace-assisted heating methods and $ZnCl_2$ as an activating agent. Muffle furnace-assisted heating has an advantage over microwave heating in terms of increasing surface area, pore volume, thermal stability, and fixed carbon percent. Microwave heating generates low surface area ($9.85\,m^2/g$) and pore volume ($0.01\,cm^3/g$) activated carbon (MW-THAC), while muffle furnace heating forms activated carbon …

Funding

This research was funded by Universiti Sains Malaysia (USM) Short term grant number 304/PTEKIND/6315581. …

Ethical approval

Not Applicable. …

Consent to participate

Not applicable. …

Consent to Publish

Not applicable. …

CRediT authorship contribution statement

Khalid Siraj: Writing – original draft, Supervision, Investigation. **James Simon Aballa:** Methodology, Investigation, Data curation. **Mohammed Danish:** Writing – review & editing, Supervision, Investigation, Data curation. **Tanweer Ahmad:** Formal analysis. **Mohammad Mansoob Khan:** Writing – review & editing. **Shahnaz Majeed:** Writing – review & editing. **Birtukan Adane:** Formal analysis. …

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. …

Acknowledgment

The authors wish to acknowledge the short-term research grant (grant number: 304/PTEKIND/6315581) from Universiti Sains Malaysia (USM). …

Recommended articles

References (48)

M. Ghorbani *et al.*
Adsorptive removal of lead (II) ion from water and wastewater media using carbon-based nanomaterials as unique sorbents: a review
J. Environ. Manag. (2020)

M. Danish *et al.*
A review on utilization of wood biomass as a sustainable precursor for activated carbon production and application
Renew. Sust. Energ. Rev. (2018)

A.S. Shamsabadi *et al.*
An investigation on the pore characteristics of dates stone based microwave activated carbon nanostructures
Diam. Relat. Mater. (2021)

M.R. Zakaria *et al.*
Production of biochar and activated carbon from oil palm biomass: current status, prospects, and challenges
Ind. Crop. Prod. (2023)

T. Ahmad *et al.*
Prospects of banana waste utilization in wastewater treatment: a review
J. Environ. Manag. (2018)

A. Nasrullah *et al.*
Mangosteen peel waste as a sustainable precursor for high surface area mesoporous activated carbon: characterization and application for methylene blue removal
J. Clean. Prod. (2019)

N.S. Sulaiman *et al.*
Optimization of activated carbon preparation from cassava stem using response surface methodology on surface area and yield
J. Clean. Prod. (2018)

Y. Shen *et al.*
High effective adsorption of Pb(II) from solution by biochar derived from torrefaction of ammonium persulphate pretreated bamboo
Bioresour. Technol. (2021)

M. Danish *et al.*
Characterization and adsorption kinetic study of surfactant treated oil palm (Elaeis guineensis) empty fruit bunches
Desalin. Water Treat. (2016)

G.-J. Jiao *et al.*
Recent advances and challenges on removal and recycling of phosphate from wastewater using biomass-derived adsorbents
Chemosphere (2021)

View more references

Cited by (8)

Synthesis of diatomite/Fe3O4/Teff straw activated carbon composite adsorbent for Cr(VI) removal from wastewater
2025, Results in Chemistry

Show abstract

Insight into the efficient removal of Cu (II) from aqueous solutions on a biochar-alginate composite
2025, Process Safety and Environmental Protection

Show abstract

The Role of the Surface Energy of Tannin-Based Adsorbent Materials on the Lead Removal Capacity in Contaminated Water ↗
2025, Chemistry Methods

Synthesis and characterization of corn cob activated carbon for Pb(II) adsorption with real-time monitoring using internet of things ↗
2025, Physica Scripta

Synthesis, characterisation of agricultural biomass derived activated carbon and its applications ↗
2025, Materials Research Express

Highly Efficient and Environmentally Friendly Walnut Shell Carbon for the Removal of Ciprofloxacin, Diclofenac, and Sulfamethoxazole from Aqueous Solutions and Real Wastewater ↗
2024, Processes

View all citing articles on Scopus ↗

View full text