Unlocking the environmental potential of highly porous Biochar synthesized from waste biomass via carbonization"

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OF

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IN

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Submitted by
Paridhi
(24/IBT/06)

Under supervision

Prof. JAI GOPAL SHARMA



DEPARTMENT OF BIOTECHNOLOGY

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi 110042

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I would like to extend my thanks to Mr.CB Singh and Mr. Jitendra Singh and other non-teaching staff members for supporting me although the project tenure.

Finally , I am thankful to my family and friends for continuous engagement throughout the process of project. The accomplishments would not have been possible without them.

Paridhi

DECLARATION

I, Paridhi (Roll No. 24/IBT/06), a student of Master of Technology (Industrial Biotechnology), hereby declare that the Project Dissertation titled **"Unlocking the environmental potential of highly porous Biochar synthesized from waste biomass via carbonization"** submitted to the Department of Biotechnology, Delhi Technological University, Delhi, in fulfilment of the requirements for the award of the degree of Master of Technology, is original and has not been copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma, Associateship, Fellowship, or any other similar title or recognition.

Place: Delhi

PARIDHI

CERTIFICATE

I hereby certify that the Project Dissertation titled **"Unlocking the environmental potential of highly porous Biochar synthesized from waste biomass via carbonization"**, submitted by Paridhi, Roll No. 24/IBT/06, Department of Biotechnology, Delhi Technological University, Delhi, in partial fulfilment of the requirements for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge, this work has not been submitted, in part or full, for any degree or diploma to this University or elsewhere.

Dr. Jai Gopal Sharma
Supervisor
Department of Biotechnology
Delhi Technological University

Prof. Yasha Hasija
Head of Department
Department of Biotechnology
Delhi Technological University

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Paridhi
(2K24/IBT/06)

Date:

Abstract

The carbon-rich porous is Biochar which is produced by thermal carbonization of biomass under oxygen-limited conditions. Its composition, which typically includes fixed carbon, mineral ash, and diverse functional groups, high porosity, adsorption ability, and chemical stability. These features have made biochar attractive material for a range of applications such as soil improvement, pollutant removal, carbon sequestration, renewable energy system and catalyst support. Beyond these uses, Biochar plays a vital role in advancing development by transforming low value biomass into high value products that support waste valorization and environmental protection. Biochar enhances soil fertility by improving nutrients and water retention, supporting agricultural productivity in a sustainable manner. Synthesis of biochar is followed by operational parameters optimization including Temperature, Time and Dosage, which shows significant effect on the physiochemical properties of synthesized biochar. Furthermore, this study includes doping of biochar as innovative steps to alter the surface chemistry, pore distribution, charge density and electronic properties of biochar, creating tailored materials, which enhanced functionality. Results revealed that a highly porous, rich in functionality and surface area biochar is formed. Overall, the study demonstrates biochar as a low cost, eco-friendly, and high-performance material capable of addressing complex challenges in sustainability, environmental remediation and clean energy.

Keywords: - Carbonization, Biochar, Waste Valorization, Sustainability, Porous material

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List of Symbol Abbreviations

- Co Initial concentration of adsorbate (mg/L)
- Ce -Equilibrium Concentration of adsorbate after adsorption(mg/L).
- *qe*- Adsorption capacity at equilibrium (mg/g).
- V - Volume of solution(L).
- W - Weight of adsorbent (g)
- pH - Potential of hydrogen
- Absorbance
- T- Temperature
- t- contact time (min)
- m^2/g - Surface area per gram of adsorbent
- cm^{-1}- Wavenumber used in FTIR analysis
- ppm -parts per million
- mg/L- Milligram per liter
- mg/g - Milligram per gram
- °C – Degree Celsius

ABBREVIATIONS

Abbreviation	Full Form
FTIR	Fourier Transform Infrared Spectroscopy
BET	Brunauer-Emmett-Teller
UV-Vis	Ultraviolet-Visible-Spectroscopy
DPC	1,5 -Diphenyl carbazide
Cr(vi)	Chromium (vi)
ppm	Parts per million
pH	Potential of Hydrogen
HCl	Hydrochloric acid
mg/L	milligram per litre
mg/g	Milligram per gram
nm	Nanometer
min	Minute
WWT	Waste water Treatment

Chapter 1

INTRODUCTION

1.1 Energy Consumption

Due to a 4.3% increase in electricity use from cooling, industrial operations, electric mobility, data centers, and AI applications, global energy demand grew by 2.2% in 2024, reaching about 650 exajoules (EJ), exceeding the 1.3% average annual growth over the previous ten years. While advanced economies had a little 1% increase after earlier declines, emerging and developing economies in Asia, such as China and India, accounted for more than 80% of this expansion

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1.2 KEY FUEL SOURCE TRENDS

1. Natural gas accounted for 28%, coal for 15%, oil for 11% and nuclear for 8% of supply increases, with renewables driving 38%.
2. As growth was strained by vehicles and normalized post-pandemic patterns, oil usage increased by 0.8% to 193 EJ, lowering its historical share below 30%.
3. Driven by industrial and power demands in Asia and the US, natural gas hit peak levels, surging 2.7%.
4. China and India saw 1.2% increase in coal use, mostly for production of energy during heatwaves.
5. CO2 output: In contrast to the 3.2% GDP growth, Co2 emissions from energy increased by 0.8% (300 million tons).

1.3 Disadvantages of fossil fuel:

1. Climate change and global warming, fossil fuel burning release greenhouse gases that trap heat and cause temperature increase of earth which leads to extreme weather, sea level rise loss of biodiversity, and leads to threat to food and water security.
2. Air and water pollution, combustion of fossil fuel emits toxic pollutants like SO2, NO2, and particulate matter which damage air quality and respiratory disorders. Water resources suffer from contamination, oil spills, acid rain, and run off from mixing which harms aquatic life and ecosystems.
3. Habitat destruction and biodiversity loss,
4. Human health risks and pollution leads to various respiratory disorders like asthma, lung cancer, and heart diseases. Emission from fossil fuel dipropionate affect vulnerable population.

1.4 RENEWABLE ENERGY

For production of energy responsibly and reduce reliance on fossil fuels, renewable energy sources such as solar, wind, hydropower, biomass, and geothermal – harness naturally replenishing resources.

1. Wind turbines onshore or offshore farms use the kinetic energy of air currents, solar panels use photovoltaic cells to run sunlight into electricity.
2. Utilizing flowing water through dams or run-off -river systems, hydropower is the most popular renewable energy source in united states.
3. Plants grow and reabsorb CO2, biomass converts organic waste, such as wood or crops, into biofuels and heat, improving carbon neutrality.
4. Tidal energy from ocean motions
5. Geothermal energy uses earth's interior heat to generate baseload electricity.

1.5. INTRODUCTION TO BIOMASS

Lignocellulosic biomass in plant dry matter derived from plants, animals and microorganisms. Biomass can be used as a source of renewable energy.

Biomass Types:

1. Agricultural waste and residues from biomass crops (corn stalks, sugarcane bagasse).
2. Municipal Waste Biomass: Organic waste originating from homes and businesses.
3. Industrial Biomass: Textile, brewery, and food industry waste.
4. Forestry Biomass: sawdust, wood chips, and forestry leftovers.

1.5 The composition of elements in biomass: -

1. 45–55% carbon (c)
2. 5-7% hydrogen (H)
3. 35–45% oxygen (O)
4. 0.5–2% nitrogen (N)
5. 0.1–1% Sulphur (S)
6. 1-10% ash

1.6 COMPOSITION OF BIOMASS.

The main constituents of biomass are especially in materials derived from plants, are cellulose, hemicellulose, and lignin.

Cellulose:

1. Composition: glucose units ($C_6H_{10}O_5$)
2. Structure: Crystalline, linear polymer
3. Function: Offers stiffness and strength
4. Content: 30–40% agricultural biomass and 40–50% woody biomass

Hemicellulose:

1. Composition: $C_5H_8O_4$ (units of galactose, arabinose, and xylose)
2. Structure: Amorphous, branching polymer
3. Cross-linking cellulose fibers is its function.

Lignin:

1. Composition: phenolic units ($C_{31}H_{34}O_{11}$)
2. Structure: Three-dimensional, intricate network
3. Function: Offers water resistance and stiffness
4. Composition: 10–20% agricultural biomass and 15–25% woody biomass

1.6 BIOCHAR

Biochar is a stable carbon-rich, porous substance which is formed by formed by thermally breaking down of biomass known as pyrolysis.

It has many uses like waste management, agriculture, environment restoration, and climate change mitigation, it has attracted a lot of attention from around the world in recent years.

Agricultural leftovers, forestry waste, animal manure, sewage sludge, and industrial organic waste are just a few of the cheap and plentiful feedstocks that are commonly used to make biochar. This turns garbage into a product with added value, making it sustainable substance.

Carbonization is also a method for transformation of biomass or organic material into a solid that is rich in carbon by heating it to high temperature with little to no oxygen. A stable carbon structure is left behind after this process eliminates moisture, volatile substances, and non-carbon elements like hydrogen, oxygen, and nitrogen. Carbonization is process of making biochar, charcoal, activated carbon-, and carbon-based products.

The distinctive physiochemical characteristics of biochar, such as its large surface area, Strong aromatic carbon structure, mineral content, surface functional groups, and porosity, have sparked scientific interest in the material. Because of these qualities, biochar is excellent carbon sequestration, soil conditioning, pollutant adsorption, and soil fertility enhancement.

When biochar is added to soil, it promotes nutrient retention, microbial development, water retention, and greenhouse gas emission.

Heavy metals, dyes, pesticides, medications, microplastics, and organic contaminants sore frequently removed from contaminated water and soil using biochar in environmental engineering. This type of feedstock, pyrolysis temperature, particle size, surface chemistry, and pH level all affect its adsorption efficacy. According to recent research, biochar surface area, active sites, redox characteristics, and catalytic behavior are greatly increased when it modified with metals, minerals, or chemical agents (such as Fe, Si, Mn, Mg, KOH, H_3PO_4, or clay materials),

The selection of biomass, pre-processing, pyrolysis at a regulated temperature, post-treatment, and characterization are some of the crucial phases in the manufacture and research of biochar.

SEM, FTIR, XRD, BET, TGA, and elemental analysis are common characterization techniques that aid in comprehending the biochar structure, composition, stability, and adsorption behavior

All things considered, biochar is a viable sustainable solution that connects the domains of waste management, renewable sources, environmental cleanup, and climate resilience.

Its ability to address several global issues, such as pollution control, soil degradation, energy efficiency, and carbon management, is shown in the growing interest in research globally.

Chapter -2

Literature review

Biochar has gained global attention as a sustainable material for agriculture, environmental remediation, and catalysis. Scient metric studies show that research activity has increased sharply, with agriculture-related applications dominating. *Meena et al.* (2025) found that most studies focus on soil fertility, pollutant immobilization, carbon sequestration, and biochar amended crop systems, indicating strong interest in biochar's role in the circular bioeconomy.

1. **Production of Biochar and Process characteristics:**

Conditions during pyrolysis have a significant impact on biochar's characteristics and functionality

According to Tripathi et al. (2016), yield, aromaticity, and functional group distribution are determined by temperature, residence duration, and heating rate, which affects the applicability of biochar for environmental applications. Increased carbonization temperature of apple tree branches resulted in increased fixed- carbon content and more stable carbon structures, but overall yield dropped, as it is common for lignocellulosic biomass, according to yang et.al (2020)

Chemical and textural properties are also determined by the type of biomass. Tun et al. (2020) demonstrated that activated carbons with well- developed pore system may be produced from coconut and peanut shells, highlighting the importance of feedstock selection in the manufacture of high-performance biochar. This was further supported by Rabata et al. (2025), who show how temperature -dependent kinetics directly affect reactivity and adsorption potential by altering the physiochemical characteristics of biochar

.

2. The structural properties and reactivity of Biochar

According to Qin et al. (2020), a higher degree of carbonization increases porosity and reactivity but decreases oxygenated functional groups, which are crucial for soil nutrient retention and metal binding. These trade-offs emphasize the necessity of tailoring pyrolysis setting based on intended use (catalysis, adsorption, or soil amendment).

Research themes have changed from basic production studies to functionalization and engineering biochar systems, especially after 2015, according to scientific metric evidence from Jiao et al. (2021). Supporting the movement toward more advanced materials

3. Composites enhanced with Metal and Modified Biochar:

Biochar that has been altered with material has become a potent tool for cleaning up the environment. Wang et al. (2022) created an iron-biochar composite with peanut shells and sludge ash, showing effective elimination of arsenic. The authors highlighted how silica stabilizes the formation of reactive iron species, which makes the composite very successful in treating water.

The catalytic activity of Mn -doped biochar system is also very high. Mn-modified magnetic biochar efficiently activates persulfate for antibiotic breakdown, as Huang et.al (2020) showed, indicating significant potential for wastewater treatment. These investigations demonstrate the benefits of multi-metal doped biochar's in catalytic remediation, oxidation, and adsorption. After reviewing more general catalytic applications, Lyu et al. (2020) concluded that biochar and its composites serve as effective supports. They are adaptable catalysts for environmental engineering because of their excellent stability, surface tunability, and capacity to attach metal species

Study / Author (Year)	Research Focus	Method / Materials Used	Major Findings	Relevance to Present Work
Meena et al. (2025)	Scient metric trends of biochar in agriculture	Bibliometric & scient metric analysis	Rapid global rise in research; focus on soil fertility, pollution reduction, sustainable practices	Supports importance of biochar research; identifies research gaps
Tripathi et al. (2016)	Effect of pyrolysis parameters on biochar	Review of pyrolysis temperature, heating rate, biomass type	Higher temperature = higher carbon content, lower yield; parameters influence physicochemical properties	Helps optimize pyrolysis conditions for high-quality biochar
Yang et al. (2020)	Carbonization of apple branches	Slow pyrolysis at 300–700°C	High temperature increases fixed carbon, reduces yield; improves structural stability	Guides selection of carbonization temperature for stable char
Wang et al. (2022)	Fe–biochar composite from sludge ash & peanut shell	Co-pyrolysis of sludge ash + peanut shell	Silica stabilizes Fe species; high arsenic adsorption efficiency	Supports Fe–Si modified biochar concept for water purification
Rabata et al. (2025)	Pyrolysis kinetics & temperature influence	Kinetic modeling + temperature variation	High temperature → more aromatic, more reactive biochar; lower yield	Important for designing catalytic and adsorption-active biochar
Tun et	Activated	Pyrolysis +	Biomass type affects	Helps in selecting biomass

Study / Author (Year)	Research Focus	Method / Materials Used	Major Findings	Relevance to Present Work
al. (2020)	carbon from coconut & peanut shells	activation	pore structure; good surface area and porosity achieved	with natural lignocellulosic advantage
Qin et al. (2022)	Carbonization of lignocellulosic biomass	Pyrolysis at varying temperatures	Increased porosity at high temperature but loss of functional groups	Helps balance porosity vs. functional groups in composite synthesis
Jiao et al. (2021)	Scient metric review of biochar preparation	Bibliometric mapping of 2006–2019 publications	Research shift toward engineered/modified biochar's after 2015	Supports your focus on Fe–Si–Mn modified biochar
Huang et al. (2020)	Mn-doped magnetic biochar for catalysis	Mn impregnation + pyrolysis	High catalytic activity in persulfate activation; effective antibiotic degradation	Justifies using Mn for improved catalytic performance
Lyu et al. (2020)	Biochar and composites in catalysis	Review of catalytic applications	Biochar acts as catalyst/support; good stability & tunable surface	Strengthens foundation for catalytic application of your composite

Table-2.1 Literature Review

Chapter 3

Materials and Methodology

1.Materials

Grinder, Sieves, Oven, Furnace, weighing machine, petri dish, centrifuge, glass vials, spatula, pipette, sucker, beakers, trays.

2.Chemical used:

Ethanol, water**.**

3.1. Preliminary Steps

The biomass was collected from fields and mulched into small pieces. Furthermore, it is washed with water and dried in oven at 60ºC (left overnight).

3.2. Biomass Preparation

Raw biomass was first cleaned by washing it 2-3 times with distilled water to eliminate surface dust and impurities. The washed material was allowed to dry under shade for 3–4 h, followed by oven-drying at 80 °C for 12 h to ensure complete removal of residual moisture. The dried biomass was then grinded into fine powder, sieved biomass to remove fibrous particles and dust and stored in airtight containers for further use.



Biomass collection



washing by distilled water and dried at 80°C



Grinding



Grinded biomass



Screening

BIOMASS PREPARATION

Fig 3.1- Biomass Preparation

3.4. Pyrolysis

The impregnated biomass samples (5 g each) were subjected to pyrolysis in a tubular furnace under nitrogen flow. The temperature was raised to 300 °C at a the rate of 10 °C min^{-1} and maintained for 30 min.(*Alimu et al (2025*)) After cooling to room temperature under nitrogen, the resulting biochar's were collected, ground into fine powder, and stored in airtight vials for subsequent characterization and adsorption studies.

Fig 3.2 Biochar Preparation and Doping



Carbonization (300-600°C)



Biochar formation



Biochar doping with metals



Centrifugation 2000rpm@ 2min



Drying



Storage

3.5. Adsorption

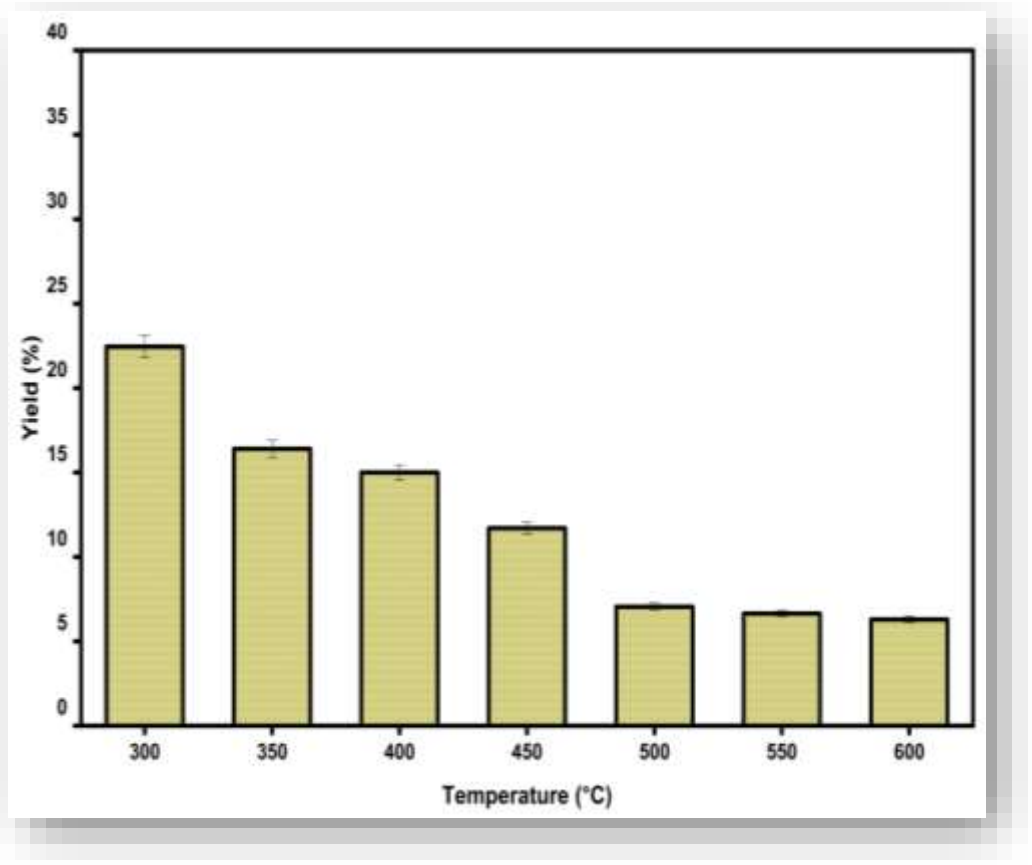
Heavy Metals and Dyes are used to test the efficiency of biochar.

Chapter 4

Parameter optimization:

Temperature Optimization

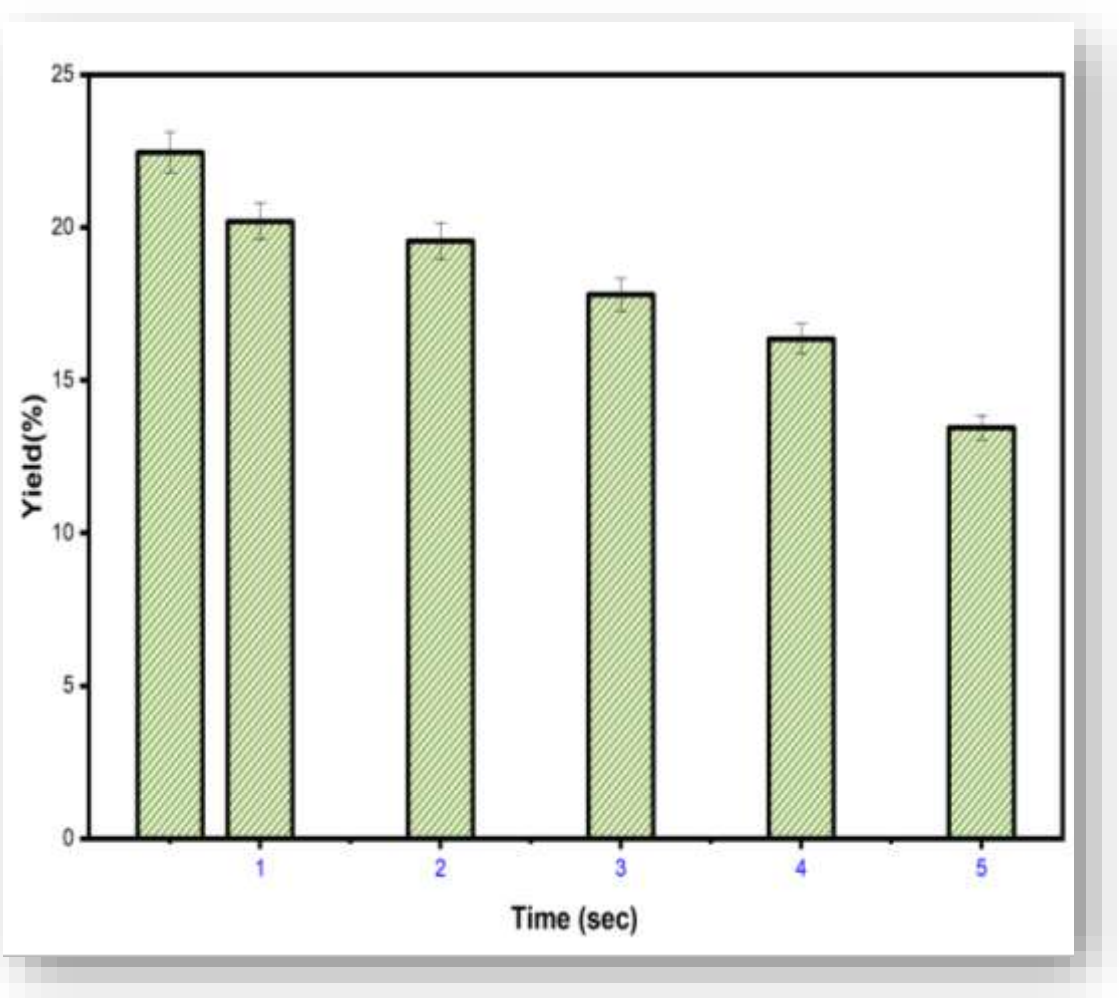
As the carbonization temperature rose, the biochar yields all progressively dropped from 22.4 weight percent to 6.3 weight percent. Higher pyrolysis temperature dropped from 24.5 weight percent 6.3 percent. Higher pyrolysis temperature may have generated more volatile chemicals and encouraged the secondary breakdown of biochar, which could be the main cause of this.



Grapgh 4.1 Effect of Temperature

2.EFFECT OF RESIDENCE TIME

The yields are made from peanut shells at various residence times (1.0, 1.5, 2.0, 2.5, and 3.0 hours). The biochar yield dropped from 20.2%to 17.8% when the residence time was extended from 1.0 to 3.0 hours. This was mostly because prolonged residence time caused the to break down further, releasing more volatile chemical compound.



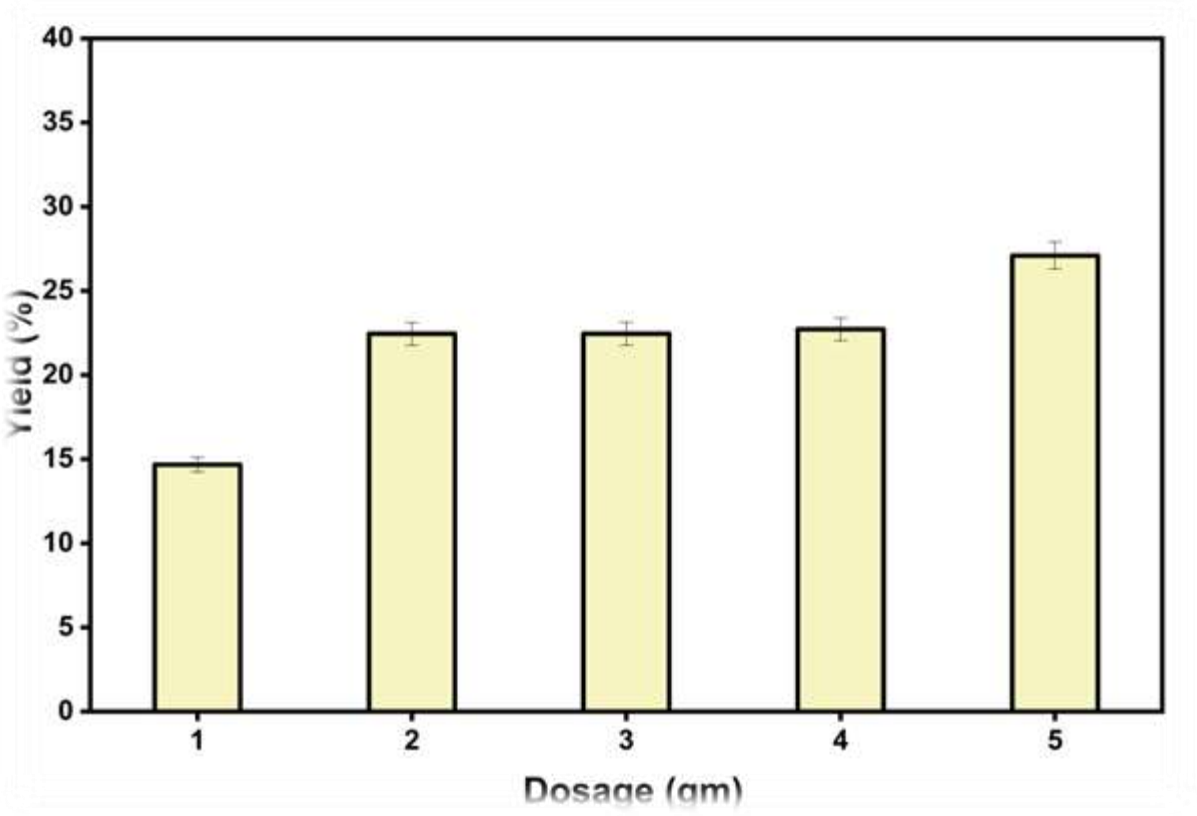
Graph 4. 2.Effect of residence time

EFFECT OF DOSAGE

Increased biomass dose increases the production of biochar primarily because it increases the amount of material available for conversion and improves carbon retention during carbonization.

More organic matter is accessible for thermal breakdown when biomass dosage increases, which promote reactions in the presence of moderate amount of ash or minerals, which promote reactions that prefer the creation of solid biochar over volatile compounds.

Additionally, a greater dosage can increase the effectiveness of carbon conversion, particularly in the presence of moderate amounts of ash or minerals, which promote reactions that prefer the creation of solid biochar over volatile compounds



Graph -4.3 Effect of dosage

Chapter- 5

Characterization

Using Brunauer-EmmettAnalysis and Fourier Transform Infrared Spectroscopy; the physiochemical features of synthesized biochar adsorbent were examined to look into the materials adsorption capabilities, surface functional groups, and pore characteristics

FTIR Study :

Fourier Transform Infrared Spectroscopy (FTIR) analysis was performed to identify the functional groups present on the surface of the synthesizes biochar sample and to understand chemical modifications occurring during the pyrolysis and metal doping process. FTIR is an important characterization technique widely used for determining surface chemistry, bonding interaction, and the presence of oxygen-containing functional groups in carbon-based materials(Qin et al.,2022;Lyu et al.,2020) The obtained FTIR spectrum revealed several characteristic absorption bands corresponding to organic and inorganic functional groups.

A broad absorption peak observed around 3350 $^{-1}$ corresponds to O-H stretching vibrations, which indicate the presence of hydroxyl groups and adsorbed water molecule on biochar surface. Hydroxyl functional groups are responsible for increasing hydrophilicity and enhancing adsorption interaction with pollutants through hydrogen bonding(Afshar& Mofatteh,2024:Yusuff et al.,2022).

The peak was observed near 2920 cm^{-1}. Correspond to aromatic C=C stretching vibrations or carbonyl groups. This peak indicates the formation of aromatic ring structure during pyrolysis, which contributes to structure stability and chemical resistance of the biochar. Aromatic structures are considered important for electron transfer properties and adsorption behavior of modified biochar composites. The formation of condensed aromatic structure confirms successful thermal decomposition and carbon enrichment(Tripathi et al.,2016 Ramnhatla et al.,2025).

Another peak observed around 1380 $cm^{-1}$is associated with C-O stretching vibrations of phenolic, alcoholic, or carboxylic functional groups. Oxygen containing functional groups plays an important role in enhancing surface reactivity and ion-exchange capacity of biochar materials. These groups improve the interaction between biochar and heavy ions through

electrostatic attraction and complexation mechanism on surface.

The adsorption band under 1030cm^{-1} corresponding to Si-O stretching vibrations and oxygenated surface functionalities. The presence of Si-O bonds indicates incorporation of silica-modified biochar's improved stability, porosity, and adsorption performance for environmental applications such as WWT and soil remediation (Wang et al.,2022;Qin et al.,2022). Furthermore, the low-frequency peaks observed in range of 400-700 cm-1. Corresponding to metal-oxygen bonds such as Fe-O or Mn-O vibrations. These peaks confirm the successful doping or loading of metal oxides onto biochar surface. The incorporation of metal species can significantly activity, magnetic separation properties, and pollutant degradation efficiency of the composite material. The formation of metal-oxygen bonds indicates strong interaction between the biochar surface and metal particle during synthesis(Huang et al.,2020;Jiang et al.,2023)

Hence FTIR analysis confirms the formation of successful formation of a multifunctional biochar composite containing hydroxyl, aromatic, oxygenated, silicate, and metal oxide functional groups. The presence of these functional groups enhances physiochemical properties of synthesized biochar and makes it suitable for various applications like WWT, catalysis, and environmental remediation.(Lyu et al.,2020; Al Saadi et al.,2026).

The observed peaks also indicate the modification process was successful and resulted in improved surface chemistry of biochar material. Overall, the second FTIR spectrum of modified biochar demonstrates stronger metal-oxygen interactions, enhanced silica- bonding, increased oxygen- containing functional groups, involved aromatic carbon -structure, and more effective chemical modification as compared to raw biochar (Rahman et al.,2024, Zhang et al.,2023)

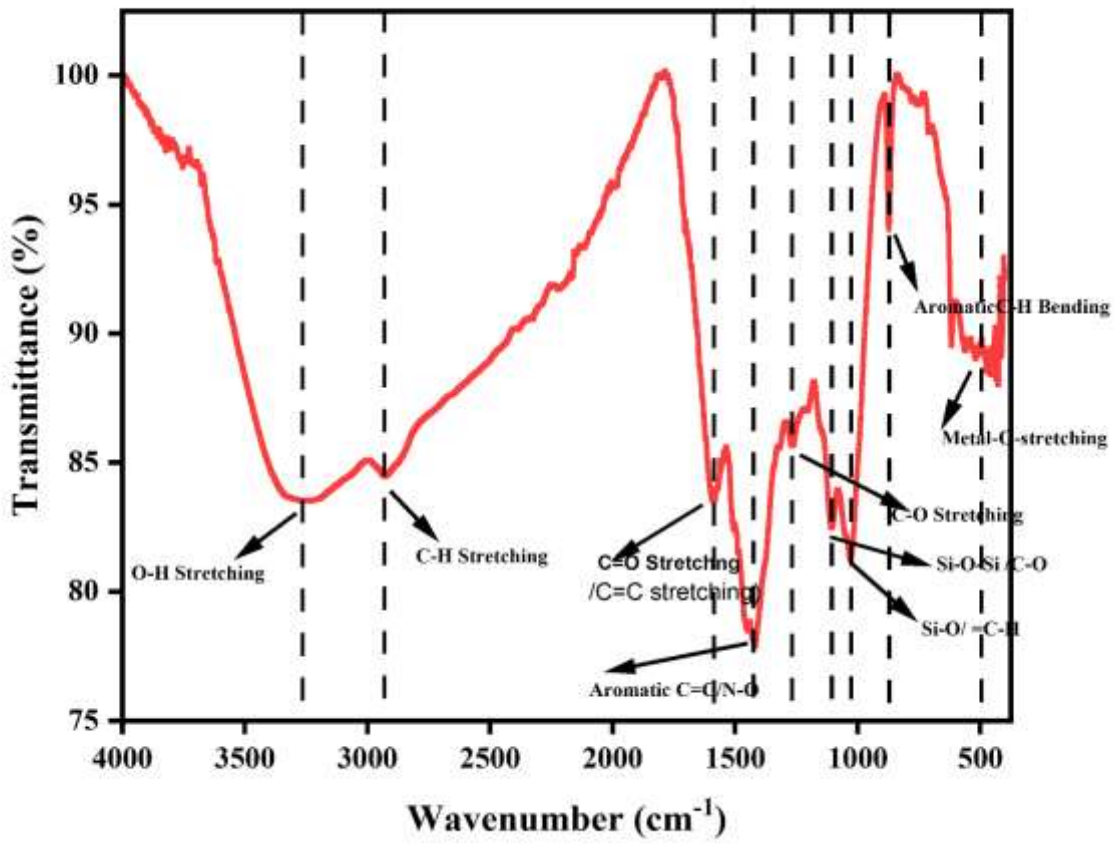


Fig 5.1- FTIR PLOT OF RAW BIOCHAR

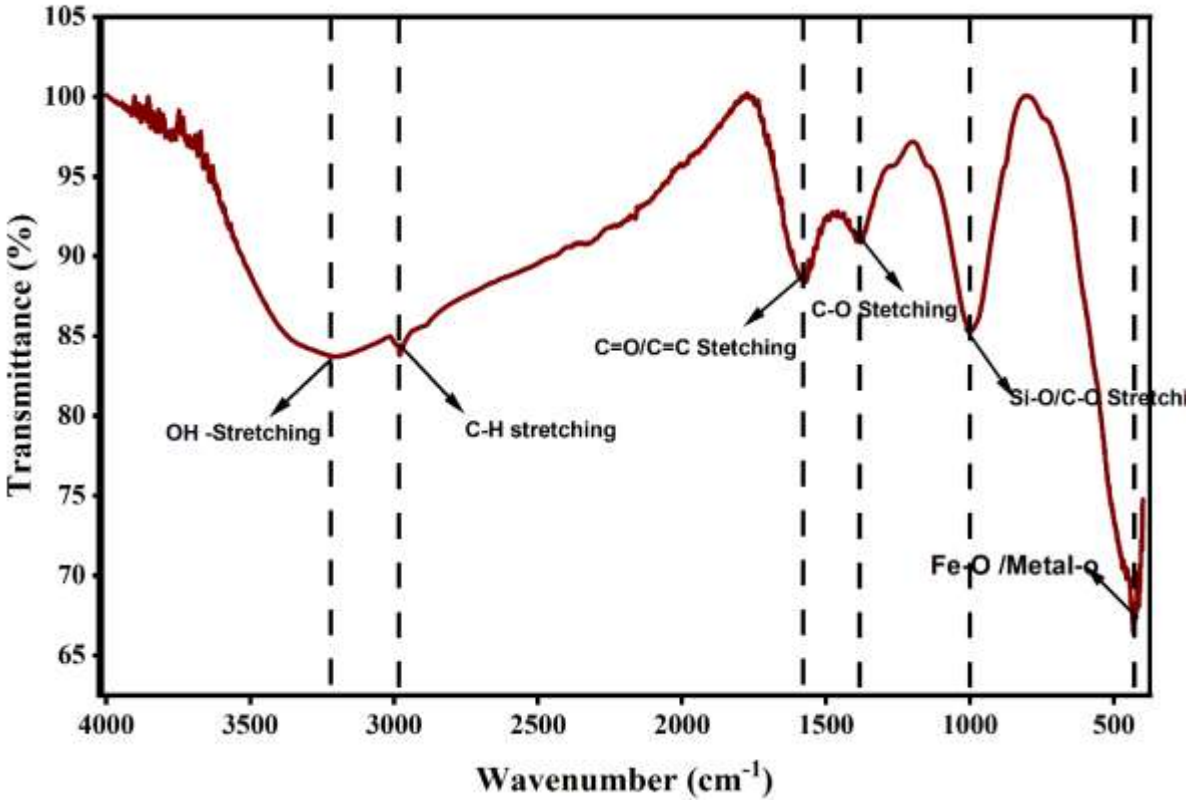


Fig. 5.2 -FTIR PLOT OF DOPED BIOCHAR

BET STUDY

The surface area, pore volume and the pore-structure of the prepared biochar was analyzed by using BET analysis. The adsorption -desorption isotherm results confirmed that the synthesized biochar possesses a well-developed porous structure, which is considered an important property for adsorption application. Similar characteristics of biochar material have also been reported in previous studies related to wastewater treatment and pollutant removal(Tripathi et al.,2016; Qin et al.,2022).

The obtained biochar showed a comparatively large surface area with the presence of both type of micropores and mesopores. These pores increase the available adsorption sites and help pollutant molecules easily diffuse into into the internal structure of adsorbent. Asa a result, the adsorption efficiency of biochar gets significantly improved (Afshar &Moffatteh, 2024; Rambhatla et al.,2025)

The BET result is that tri-doped biochar has maximum surface area is 44.723 m^2/g. The synthesized biochar has suitable textual properties for removal of tartrazine dye and Cr(VI) from the aqueous solution. The higher surface area and pore volume enhances the interaction between adsorbent surface and pollutant molecules, leading to better adsorption performance. Similar findings have been observed in earlier studies involving biochar and activated carbon materials for dye and heavy metal adsorption (Gautam et al.,2015; Yusuff et al., 2022; Deng et al.,2024),

Overall, the BET characterization suggests that prepared biochar can be considered a promising, low-cost, and suitable adsorbent for wastewater treatment applications. Its porous structure and large surface area support the effective adsorption behaviors for the removal of harmful contaminants from polluted water systems. Comparable BET characteristics and adsorption performance have also been reported in several previous studies on biochar- based adsorbents (Lyu et al.,2020; Zhang et al.,2023;Al Saadi et al.,2026).

Chapter 6
Adsorption Parameter Optimization

Batch adsorption experiments were carried out to evaluate the adsorption performance of the prepared and modified biochar for the removal of chromium(Cr VI) ions and tartrazine dye from aqueous solutions . Different operational parameters that is contact time, adsorbent dosage, pH, and initial pollutant concentration were systematically investigated to determine optimum conditions for maximum adsorption efficiency. Similar experimental approaches have been widely reported in earlier studies involving biomass -derived adsorbents for wastewater treatment applications(Gautam et al.,2015;Yusuff et al.,2024)

The adsorption studies were conducted under batch conditions using 40 ml pollutant solution in separate conical flasks. During the experiments, the pH of the solution was adjusted to the desired value after adding required amount of absorbent. The mixture was agitated using orbital shakers for specific time period to attain adsorption equilibrium. Experimental observation revealed that optimum adsorption was achieved at an initial pollutant concentration of 200ppm, contact time of 30 minutes, adsorbent dosage of 0.1g, pH 5, and room temperature conditions. These findings indicate that the adsorption efficiency is strongly influenced by solution conditions and operational parameters, which is consistent previous report on dye and heavy metal adsorption using biochar (Sari et al.,2007; Zahaf et al.,2026)

The percentage removal efficiency of pollutant was calculated by using this equation:

Removal Efficiency %= Co-Ce/Co *100

Co- initial conc. of adsorbate

Ce – equilibrium concentration after adsorption

Adsorption capacity of biomass adsorbent can be determined by using:

$$qe = (Co-Ce)V/W$$

qe- adsorption capacity mg/g

V- Volume of solution

W- the amount of adsorbent used(g)

After completing adsorption process, the solutions fitltered and the remaining pollutant concentration was analyzed using UV- spectrophotometry. As DPC has high selectivity and sensitivity towards Cr(VI) ions, so DP Colorimetric method was employed. The DPC was prepared by dissolving 0.25g of diphenyl carbazide in 100ml acetone. The filtered chromium solution was mixed with reagent in 1:1 ratio which is followed by addition of few drops of hydrochloric acid which facilitate complex formation. After allowing some reaction time, a colored complex was formed which was analyzed spectrophotometrically.

For analysis , the filtrate collected after adsorption was directly transferred into UV cuvettes for absorbance measurement using UV- visible spectrophotometer. A noticeable reduction in intensity of absorbance confirms the successful removal of heavy metal. This procedure and heavy metal adsorption has been reported(Anigor et al., Gul et al.,2025).

The experimental finding suggests that the synthesized biochar has excellent amount of adsorption. Studies have similarly highlighted the effectiveness of biomass derived adsorbents for removal of dye and heavy metals, factors like pH, contact time, adsorbent dosage, and initial pollutants significantly influence adsorption behavior (Tripathi et al., 2016, Zhang et al.,2023; Al Saadi et al.,2026)

Results of Adsorption

Adsorption of Chromium(vi): Chromium is considered one of the most toxic heavy metal pollutants commonly released from the electroplating, leather tanning, textile dyeing, metal finishing, and pigment manufacturing industries. Chromium mainly exists in two stable oxidation states, trivalent chromium (Cr(III)) and hexavalent chromium (Cr(VI)), among which Cr(VI) is highly toxic , carcinogenic, mutagenic, and highly soluble in water. Due to its severe environmental and health impacts, the removal of chromium(VI) from industrial wastewater has become an important area of research in environmental remediation and wastewater treatment technologies.(Yusuff et al.,2022, Kim et al., 2025; Shi et al.,2025).

Among the various treatment techniques available chromium removal, adsorption has emerged as one of the most efficient, economical, and environmentally friendly methods due to its easy operation, low sludge generation, high removal efficiency, and reusability of adsorbents. In recent years, biomass- derived adsorbents and biochar material have attracted significant attention for adsorption of chromium (VI) because of their porous structure, large surface groups such as hydroxyl, carboxyl, and amino groups that facilitate metal ion binding.(Tripathi et al., 2016; Afsar & Mofatteh, 2024; Al Saadi et al.,2026).

In the present study, adsorption experiments were carried out using the synthesized biomass adsorbent for removal of chromium(VI) ion from aqueous solution under optimized experimental conditions. A 200-ppm chromium(vi) stock solution was prepared and 40ml of the prepared and 40ml of the prepared solution was transferred into conical for batch adsorption experiments. The pH for the solution and the flask was agitated in an orbital shaker for 30 minutes at ambient temperature to achieve adsorption equilibrium.

After completion of adsorption process, the solution was filtered and analyzed using UV-visible spectrophotometry for determination of residual chromium concentration. For spectrophotometric analysis, the 1,5-Diphenylcarbazide method was employed due its high sensitivity towards chromium (VI) ions. The DPC reagent was prepared by dissolving 0.25g of 1,5-diphenylcarbazide method was in 100 mL acetone. The filtered chromium sample was mixed with DPC solution in 1:1 ratio followed by addition of few drops of hydrochloric acid. The solution was allowed to react for several minutes for formation of a colored chromium DPC complex, which was subsequently analyzed using UV-visible spectrophotometer.(Lissy et al.,2025; Ismael et al.,2026)

The removal efficiency of chromium (vi) was calculated using the following equation:

$$Removal\ Efficiency(\%) = \frac{Co-Ce}{Co} \times 100$$

- Co represents the initial chromium concentration
- Ce represents the equilibrium chromium concentration after adsorption.

The adsorption capacity of the adsorbent can be determined by using:

$$qe = \frac{(Co-Ce)v}{W}$$

Where qe is adsorption capacity (mg/g), V is volume of solution(L), and W is adsorbent dosage (g).

The results obtained demonstrated effective removal of chromium(VI) ions under optimized conditions. The enhanced adsorption performance may be attributed to electrostatic interaction, ion exchange, surface complexation, and pore -filling mechanism occurring between chromium ions and active functional groups present on biomass surface. The adsorption efficiency was influenced by pH, as acidic condition favor the protonation of adsorbent surface sites and improve attraction toward negatively charged chromium species. (Sari et al., 2007; Zhang et al.,2023; Rajani et al.,2025).

The present finding indicates that the synthesized biomass adsorbent possesses considerable potential for application in industrial wastewater treatment.

The low-cost nature, Eco-friendly characteristics, and effective adsorption behavior of the biomass material makes its promising adsorbent for the removal of toxic heavy metals from contaminated water systems. (Deng et al.,2024;Rathi et al.,2025).

Cr(VI)	Abs.	Ce	Co-Ce	Ad. Cap.	Removal Eff.
Char	1.053	2.65842	197.342	78.936632	98.6707902
Tri	0.642	1.6208	198.379	79.351679	99.18959859
Mn	0.858	21.6612	178.339	71.335521	89.16940167
Si	1.202	3.03459	196.965	78.786165	98.48270639
Fe	1.495	3.7743	196.226	78.49028	98.11285029

Table 6.1 Adsorption of chromium to heavy metal chromium

Where Co -initial concentration of biochar.

Ce- concentration of biochar after adsorption.

Adsorption capacity is represented by qe

Removal efficiency is in %

Conclusion

In this work, tri-doped biochar was effectively produced and can be used as adsorbent to remove chromium from aqueous solution. The produced biochar showed notable adsorption effectiveness under ideal experimental circumstances. According to adsorption studies, 200 ppm starting concentration, contact time of 30 minutes , 0.1 g of adsorbent dose, pH 5, and room temperature were found to be ideal adsorption conditions.

Tri-doped biochar has shown maximum adsorption due functional groups and porous shape gives it a strong attraction for chromium (vi) ions. The presence of hydroxyl, carbonyl and carboxyl groups- which actively took part in chromium adsorption by surface complexation attraction was verified by FTIR , ion -exchange, and electrostatic attraction was verified by characterization methods (Huang et al.,2020; Zhang et al.,2023).

The biochar's increased surface area and porous character, which offered more active adsorption sites for elimination of chromium(vi) removal (Qin et al., 2022;Rambhatla et al.2025).The effective reduction of chromium (vi) ions upon adsorption is confirmed by successful analysis of residual chromium content using UV-visible spectrophotometry with 1,5-Diphenylcarbazide reagent.The result indicates that tri-doped biochar can be regarded as an effective, economical and environmentally acceptable adsorbent for industrial wastewater treatment and heavy metal remediation.(Yusuff et al.,2022; Al Saadi et al., 2026).

b).Adsorption of Tartrazine Dye on Biochar

The culinary, textile, cosmetic, pharmaceutical, and printing sectors all employ tartrazine , a synthetic azo color. Due to its widespread use, tartrazine has been released into aquatic habitats. Through wastewater streams and industrial effluents. Tartrazine is resistant to biodegradation and may have negative impacts on aquatic life as well as health due to its complex aromatic structure and strong chemical stability .Therefore, sustainable water management and environment preservation depend on efficient removal of tartrazine dye from wastewater.(Gautam et al., 2015; Zahaf et al.,2026).

Because of its simplicity, high efficiency, low operating cost, and the convenience of use, adsorption can regard as one of the most cheap and successful wastewater treatment process for dye removal. Due to their porous structure, wide surface area and abundance of surface functional groups including hydroxyl, carboxyl, and carbonyl groups, biochar-based adsorbents made from biomass materials have recently attracted a lot of attention for dye adsorption applications. Similar concerns regarding dye and heavy metal contamination have been reported in studies (Afshar & Moffatteh, 2024; Al Saadi et al.,2026).

In Current study, tartrazine dye was removed from aqueous solution using biochar made from biomass material as adsorbent under ideal experimental circumstances. The batch adsorption approach was used to conduct adsorption studies on an 1800 ppm stock solution of tartrazine colour. Each experiment involved transferring 40 mL of dye solution into a conical flask and adjusting the solutions pH to 5 , which was determined to be optimal for maximum dye adsorption.

After that dye solution was mixed with 0.1 g charcoal adsorbent, and the flask was shaken in an orbital shaker for 30 min at room temperature to achieve adsorption equilibrium. Through electrostatic attraction, pore diffusion, hydrogen bonding andπ-$\pi - \pi$ interactions, dye molecules interacted with biochar's surface-active adsorption sites during shaking.

The solution was filtered once d, and the filtrate was gathered into test tubes for UV-visible spectrophotometer examination. By measuring the filtrates absorbance at its distinctive wavelength, the remaining tartrazine dye content was ascertained. After adsorption, the absorbance intensity decreased, indicating dye molecules from the aqueous solution. This was reported in previous studies (Gul et al.,2025;Lebbai et al., 2025)

The solution was filters once d, and the filtrate was gathered into test tubes for UV-visible spectrophotometer examinations. The absorbance of the filtrate as its distinctive wavelength is used to calculate the residual concentration of tartrazine dye. The effective removal of dye molecules from the aqueous solution was verified by the drop in absorbance intensity upon adsorption. The adsorption process was finished (Gautam et al., 2015; Zhang et al.,2025).

The percentage removal efficiency of tartrazine dye can be calculated using the following equations:

$$\text{Removal Efficiency}(\%) = \frac{Co-Ce*100}{Co}$$

Where Co - Initial dye concentration

Ce - Equilibrium dye concentration after adsorption.

The adsorption capacity of biochar was calculated using the equation:

$$qe = \frac{(Co-Ce)V}{W}$$

The adsorption capacity is qe (mg/g),

V is the volume of dye solution(L),

Wis the weight of adsorbent(g).

Results of adsorption of Tartrazine Dye

Tartrazine	Abs.	Ce	Co-Ce	Ad. Cap.	Removal Eff. (%)
Char	2.904	228.212181	1571.78782	898.1644681	87.32154551
Tri	2.852	224.125737	1575.87426	900.499579	87.54857018
Mn	2.975	233.791749	1566.20825	894.9761437	87.01156953
Si	2.927	230.019646	1569.98035	897.1316306	87.22113076
Fe	2.998	235.599214	1564.40079	893.9433062	86.91115477

Table 6.2 – Result of Adsorption of Tartrazine Dye

Conclusion

Experimental study showed that tri-doped biochar can successfully be used to adsorb tartrazine dye from the aqueous solution. The produced biochar demonstrated tarata zine dye from aqueous solution. The produced biochar demonstrated significant dye removal effectiveness . The tri-doped biochar's porous structure, wide surface area , and abundance of functional group on adsorption performance. (Afshar & Moffatteh, 2024; Al Saadi et al.,2026). The existence of oxygen-containing functional groups that promoted hydrogen- bonding, electrostatic attraction, and $\pi - \pi$ interaction(Gautam et al.,2015; Gul et al.,2025).

The adsorption performance of the tri-doped biochar was mainly due to its porous structure, large surface area, and the abundance of functional group on adsorbent surface(Lebbai et al., 2025).

By adsorption methods we can confirm that tri-doped biochar has maximum adsorption capacity and removal efficiency %.for tartrazine dye removal (Zahaf et al.,2026)

CONCLUSION AND FUTURE SCOPE

- **Upscaling of biochar production:** Larger volumes are required for real applications, while small- scale lab production is helpful for study. In order to assess biochar cost, energy consumption and general viability for industry, future research may generate it on trial scale. This will assist in determining whether the procedure is suitable for commercial use.
- **Using advanced characterization techniques: Advanced** methods including XRD, XPS, SEM, TEM, FTIR, Raman, BET, and TGA can be utilized to understand how biochar functions. These provides detail regarding to metal bonding, structure, porosity, stability, and functional groups. The design and quality of metal-doped biochar enhanced by this kind of analysis
- **Application in multi-pollutant testing: To** evaluate real-world performance in wastewater and soil systems, future study can test metal-doped biochar in complicated contamination matrices (heavy metals, PFAS, dyes, medications, and pesticides,)
- **Creation of Composite Materials: Future** possibilities include creating hybrid composites for cutting-edge environmental and energy applications, such as biochar-clay, biochar-clay, biochar-polymer, biochar-polymer, biochar-graphene, or biochar-metal oxide materials.
- **Potential for carbon credits and Life Cycle Assessment (LCA):** Biochar can be positioned as a climate-positive technology by analyzing its potential for carbon sequestration, greenhouse gas mitigation, and contributing to carbon credit schemes.

REFERENCES

- Al Saadi, A., Al-Yahmadi, I., Al-Rashdi, N., Mohamed, I. I., & Al-Busaidi, I. K. (2026). Valorising mesquite biochar as a sustainable adsorbent for wastewater treatment: a critical review. *Frontiers in Chemical Engineering*, *7*, 1748096.
- Afshar, M., & Mofatteh, S. (2024). Biochar for a sustainable future: Environmentally friendly production and diverse applications. *Results in Engineering*, *23*, 102433.
- Alimu, R., Yantake, R., Jiuyang, H., Qingling, W., & Sidike, A. (2025). Preparation of blue-cyan phosphor Sr1-yAl2-xGaxSi2O8: yCe3+ for high-color-rendering white LEDs via a cation substitution strategy. *Optical Materials*, *160*, 116671.
- Aniagor, C. O., Hashem, A., Badawy, N. M., & Aly, A. A. (2023). Verification of the optimal kinetics behaviour during the methyl blue dye adsorption onto quaternized starch derivative. *Hybrid Advances*, *3*, 100047.
- Alimu, R., Yantake, R., Jiuyang, H., Qingling, W., & Sidike, A. (2025). Preparation of blue-cyan phosphor Sr1-yAl2-xGaxSi2O8: yCe3+ for high-color-rendering white LEDs via a cation substitution strategy. *Optical Materials*, *160*, 116671.
- Bhanvase, B. A., Ugwekar, R. P., & Mankar, R. B. (Eds.). (2017). *Novel water treatment and separation methods: Simulation of chemical processes*. CRC Press.
- C. Theivarasu, S. Mylsamy. "Adsorption of reactive blue 2 dye from aqueous solution by cocoa (Theobroma) cacao shell: An agro solid waste", International Conference on Green technology and environmental Conservation (GTEC-2011), 2011
- Deng, S., Ren, B., Hou, B., Deng, X., Deng, R., Zhu, G., & Cheng, S. (2024). Adsorption of Sb (III) and Pb (II) in wastewater by magnetic γ-Fe2O3-loaded sludge biochar: Performance and mechanisms. *Chemosphere*, *349*, 140914.
- Fseha, Y. H., Eniola, J. O., Sizirici, B., Stephen, S., Yildiz, I., Khaleel, A., & Adamson, A. (2024). Application of natural earth-based materials as adsorbents for the treatment of chromium (VI)-contaminated tannery wastewater: Box-Behnken and fixed-bed column optimization. *Sustainable Chemistry for the Environment*, *7*, 100127.

- Gautam, P. K., Gautam, R. K., Banerjee, S., Lofrano, G., Sanroman, M. A., Chattopadhyaya, M. C., & Pandey, J. D. (2015). Preparation of activated carbon from Alligator weed (Alternenthera philoxeroids) and its application for tartrazine removal: Isotherm, kinetics and spectroscopic analysis. *Journal of Environmental Chemical Engineering*, *3*(4), 2560-2568.
- Gautam, P. K., Shivalkar, S., & Banerjee, S. (2020). Synthesis of M. oleifera leaf extract capped magnetic nanoparticles for effective lead [Pb (II)] removal from solution: Kinetics, isotherm and reusability study. *Journal of Molecular Liquids*, *305*, 112811.
- Geng, Y., Du, Y., Guo, T., Zhang, Y., Bedane, A. H., & Ren, P. (2023). Isothermal and isovolumetric process of CO2 adsorption on nitrogen-doped biochar: Equilibrium and non-equilibrium states. *Case Studies in Thermal Engineering*, *44*, 102814.
- Gul, S., Raza, N., Naseer, M., Aziz, K., Gul, H., Minhaz, A., ... & Azzouz, A. (2025). Unveiling the adsorptive potential of Populus ciliata leaf powder for methylene blue removal from environmental samples. *RSC advances*, *15*(49), 41899-41910.
- Hu, X., Yan, L., Wang, Y., & Xu, M. (2020). Self-assembly of binary oppositely charged polysaccharides into polyelectrolyte complex hydrogel film for facile and efficient Pb2+ removal. *Chemical Engineering Journal*, *388*, 124189.
- Ismael, Y. A., Omer, D. A., Ibrahim, S. S., & Saad, D. N. (2026). Green Approach based on Micellar-Modified Kalonji Seeds Waste for Removal of Hexavalent Chromium ions and Methyl Orange Dye from Aqua. *Journal of the Indian Chemical Society*, 102470.
- Jiang, C., Huang, S., Jiang, Y., Li, Y., Miao, T., Jin, Y., ... & Wang, W. (2024). Effects of aging processes on spent mushroom Substrate-Derived Biochar: Adsorption characteristics of Cd (II) and Cr (VI). *Arabian Journal of Chemistry*, *17*(9), 105926.

- Jiang, Y., Liu, X., Huang, S., Wu, H., Liu, H., Liu, S., ... & Wang, K. (2023). Preparation of magnetic biochar and its catalytic role in degradation of Cu-EDTA by heterogeneous Fenton reaction. *Water Science & Technology*, *87*(2), 492-507.
- Jiao, Y., Li, D., Wang, M., Gong, T., Sun, M., & Yang, T. (2021). A scient metric review of biochar preparation research from 2006 to 2019. *Biochar*, *3*(3), 283-298.
- Khatoon, U. T. (2025). *Investigation of Sustainable Green Synthesis Route for Metal Oxide Nanoparticles* (Master's thesis, The University of Manchester (United Kingdom)).
- Kim, H., Kim, B. J., Ko, M. S., Kwon, O. H., Lee, S., Choi, N., & Cho, K. (2025). Arsenic removal using foundry dust: Characterization, adsorption mechanisms, and application in acid mine drainage treatment. *Environmental Research*, *283*, 122179.
- Kiran, P. R. (2026). Sustainable agriculture fundamentals.
- Lebbai, M. M., Venthan, M., Ameen, M., Mahalingam, N., Kolusu, P., Das, S., & Soundarajan, B. (2025). Adsorptive remediation of bromocresol green dye in an aqueous solution using acid activated carbon adsorbent. *Chemical Product and Process Modeling*, (0).
- Lissy, P. M., Madhu, G., & Thomas, R. M. (2025). Numerical modelling of a fixed bed column for the Cr (VI) adsorption using pyrrole coated nanocomposite. *Journal of the Indian Chemical Society*, *102*(2), 101568.
- Lyu, H., Zhang, Q., & Shen, B. (2020). Application of biochar and its composites in catalysis. *Chemosphere*, *240*, 124842.

- Madani, S., Nikfarjam, N., Mamipour, Z., & Kompany-Zareh, M. (2024). Preparation of a surface molecularly imprinted thermo-sensitive polymer for selective trypsin capture. *Microchemical Journal*, *206*, 111530
- Manyà, J. J., Roca, F. X., & Perales, J. F. (2013). TGA study examining the effect of pressure and peak temperature on biochar yield during pyrolysis of two-phase olive mill waste. *Journal of analytical and applied pyrolysis*, *103*, 86-95.
- Meena, B. P., Yadav, D. K., Yeasin, M., Shirale, A. O., Gurav, P. P., Shinogi, K. C., ... & Behera, S. K. (2025). Emerging research trends on biochar application in agriculture: A scientometric analysis. *Cleaner and Circular Bioeconomy*, *12*, 100166
- Qin, F., Zhang, C., Zeng, G., Huang, D., Tan, X., & Duan, A. (2022). Lignocellulosic biomass carbonization for biochar production and characterization of biochar reactivity. *Renewable and Sustainable Energy Reviews*, *157*, 112056.
- Rahman, M. M., Al Mamun, A., Minami, H., Rahman, M. M., Hoque, S. M., & Ahmad, H. (2024). Biochar/poly (aniline-pyrrole) modified graphite electrode and electrochemical behavior for application in low-cost supercapacitor. *Arabian Journal of Chemistry*, *17*(9), 105938.
- Rajani, M. R., Ravishankar, R., Raghavan, M. S., Priya, S., Jyothi, M. S., Ahmed, S., & Prashantha, K. (2025). Engineered ZnFe2O4/C nanocomposite for efficient hexavalent chromium removal. *Hybrid Advances*, *11*, 100518.

- Rambhatla, N., Panicker, T. F., Mishra, R. K., Manjeshwar, S. K., & Sharma, A. (2025). Biomass pyrolysis for biochar production: Study of kinetics parameters and effect of temperature on biochar yield and its physicochemical properties. *Results in Engineering*, *25*, 103679.

- Rathi, T. A., Gomase, V., Thawkar, S., Ganvir, P., Saravanan, D., & Jugade, R. (2025). Novel ACS film for efficient dual adsorption of Cr (VI) and SDS: mechanistic insights and practical applications. *Environmental Research*, *279*, 121765.
- Sari, A., Tuzen, M., Citak, D., & Soylak, M. (2007). Equilibrium, kinetic and thermodynamic studies of adsorption of Pb (II) from aqueous solution onto Turkish kaolinite clay. *Journal of hazardous materials*, *149*(2), 283-291.
- Shi, Y., Han, X., Wang, F., Zhang, Y., & Chen, M. (2025). Transport and Retention of Hexavalent Chromium With Nanoscale Iron Supported on Biochar in Water-Saturated Soils: Effects of Solution pH and Humic Acid. *Water, Air, & Soil Pollution*, *236*(8), 515.
- Shahbazi, A., Younesi, H., & Badiei, A. (2011). Functionalized SBA-15 mesoporous silica by melamine-based dendrimer amines for adsorptive characteristics of Pb (II), Cu (II) and Cd (II) heavy metal ions in batch and fixed bed column. *Chemical Engineering Journal*, *168*(2), 505-518.
- Swart, N., Lohrentz, L., & Brink, H. (2025). Optimising synthesis conditions of PANI-NSA nanotubes for chromium removal. *MRS Advances*, *10*(9), 1036-1045.

- Tripathi, M., Sahu, J. N., & Ganesan, P. (2016). Effect of process parameters on production of biochar from biomass waste through pyrolysis: A review. *Renewable and*

sustainable energy reviews, *55*, 467-481.

- Truong, D. V., Le, S. T. Q., & Bui, H. M. (2025). Research on the adsorption of Pb2+ ions and methylene blue dyes by a kapok and polypropylene fibre web. *Research Journal of Textile and Apparel*, *29*(4), 1087-1102.

- Tun, Z. M., Myat, Z. M., Win, T. T., & Maung, Y. M. (2020). Characterization of activated carbons from coconut and peanut shells biomass. *J. Myanmar. Acad. Arts Sci*, *18*, 65-74.
- Huang, D., Zhang, Q., Zhang, C., Wang, R., Deng, R., Luo, H., ... & Liu, C. (2020). Mn doped magnetic biochar as persulfate activator for the degradation of tetracycline. *Chemical Engineering Journal*, *391*, 123532.
- Wang, Q., Li, J. S., & Poon, C. S. (2022). An iron-biochar composite from co-pyrolysis of incinerated sewage sludge ash and peanut shell for arsenic removal: role of silica. *Environmental Pollution*, *313*, 120115.
- Yang, X., Kang, K., Qiu, L., Zhao, L., & Sun, R. (2020). Effects of carbonization conditions on the yield and fixed carbon content of biochar from pruned apple tree branches. *Renewable Energy*, *146*, 1691-1699.
- Ismael, Y. A., Omer, D. A., Ibrahim, S. S., & Saad, D. N. (2026). Green Approach based on Micellar-Modified Kalonji Seeds Waste for Removal of Hexavalent Chromium ions and Methyl Orange Dye from Aqua. *Journal of the Indian Chemical Society*, 102470.

- Yusuff, A. S., Lala, M. A., Thompson-Yusuff, K. A., & Babatunde, E. O. (2022). ZnCl2-modified eucalyptus bark biochar as adsorbent: preparation, characterization and its application in adsorption of Cr (VI) from aqueous solutions. *South African Journal of Chemical Engineering*, *42*, 138-145.
- Zahaf, F., Ouiddad, S., Marouf, R., & Schott, J. (2026). Equilibrium, kinetic and thermodynamic analysis of tartrazine adsorption onto raw wood sawdust as a low-cost lignocellulosic biosorbent. *Desalination and Water Treatment*, 101670.
- Zhang, K. Y., Cui, C., & Wang, L. J. (2025). Cellulose nanofiber-reinforced carboxymethyl chitosan/polyvinyl alcohol composite gels: physicochemical characterization and acid blue dye adsorption performance. *International Journal of Biological Macromolecules*, *306*, 141695.
- Zhang, X., Xu, H., Xi, M., & Jiang, Z. (2023). Removal/adsorption mechanisms of Cr (VI) and natural organic matter by nanoscale zero-valent iron-loaded biochar in their coexisting system. *Journal of Environmental Chemical Engineering*, *11*(3), 109860.

List of Conferences Presented

1. **Presented an oral presentation titled "Effect of Tri-Metal Doping on Dye Adsorption Characteristics of Peanut Shell Biochar" at the *2nd International Conference on Biomanufacturing, Bio-Innovation, and Environment Sustainability (ICBBES 2026)* organized by the Department of Biotechnology, University Institute of Biotechnology, Chandigarh University, held on 10–11 April 2026.**

2. **Presented a poster titled "Unlocking the Environmental Potential of Highly Porous Biochar Synthesised from Waste Biomass via Carbonisation" at the *International Conference on Sustainable Biotechnology and Bio-innovations (SBB-2026)* organized by Amity University Uttar Pradesh from 25–27 February 2026.**

3.



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Mr./ Ms./Dr./Prof. **PARIDHI**

from **Delhi Technological University**

has participated in the **"2nd International Conference on Biomanufacturing, Bio-Innovation, and Environment Sustainability (ICBBES 2026)"** organised by the **Department of Biotechnology, University Institute of Biotechnology, Chandigarh University, Mohali, Punjab,** India, and co-hosted by Universidad Católica San Antonio de Murcia, Spain, held on **10th–11th April 2026.**

The participant has successfully exhibited Oral Presentation in the conference, entitled

Effect of Tri-Metal Doping on Dye Adsorption Characteristics of Peanut Shell Biocha

Prof. (Dr.) Gunjan Mukherjee
Conference Chair

Prof. (Dr.) Nancy George
Conference Co-Chair



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The Biotech Research Society, India (BRSI)
International Bioprocessing Association (IBA-IFIBiop) &
Centre for Energy, Environment and Sustainability (CEES)

CERTIFICATE

This is to certify that **Paridhi** from **Delhi Technological University** has participated and presented a **poster** titled *"Unlocking the Environmental Potential of highly porous Biochar synthesised from waste biomass via carbonisation"* in the International Conference on Sustainable Biotechnology and Bio-innovations (SBB-2026) from 25th to 27th February 2026, organized by Amity Institute of Biotechnology, at Amity University Uttar Pradesh, Noida.

Prof. Sunghoon Park
Chair Professor, Ulsan-NIIST, Ulsan, South Korea
International Conference Chair

Prof. (Dr.) Rachana Singh
Chairperson, SBB 2026

Dr. Vivek Kumar Gaur
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Prof. (Dr.) Pooja Vijayaraghavan
Chairperson, SBB 2026