THE PRODUCTION OF BIO-FUEL FROM WATER HYACINTH USING $FeCl_3$ AS CATALYST THROUGH PYROLYSIS PROCESS

A Thesis
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of

Bachelor of Science in Mechanical Engineering

May 2025

APPROVAL

This is to Certify that the thesis on **"The Production of Biofuel from Water Hyacinth using $FeCl_3$ as catalyst through Pyrolysis Process"** by Md. Sujon Mridha. (ME2103025575), Shipon Chandra Bormon. (ME2103025567), MD. Jubayed Hossain. (ME2103025568), Zubayer Rahman Tareq. (ME2103025572), has been carried out under our supervisor. The thesis has been carried out in partial fulfillment of the requirements of the degree of Bachelor of Science (B. Sc.) in Mechanical Engineering of years 2024 and has been Approved as to its style and contents.

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STUDENTS DECLARATION

This is to Certify that the thesis **"The Production of Biofuel from Water Hyacinth using $FeCl_3$ as catalyst through Pyrolysis Process"** has been prepared as a part of completion of the Bachelor of Mechanical Engineering Program. I have discovered this paper very interesting, beneficial and insightful.

The entire paper is based on our practical experience. I expect this paper to be informative as well as comprehensive. This thesis paper will help me a lot in my future carrier life.

Thank you very much for your guidance and cooperation during the course without which this thesis paper cannot be completed.

Moreover, if you have any further inquiries concerning any additional information, I would be very pleased to clarify that.

Yours sincerely,

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ABSTRACT

This study investigates the production of biofuel from water hyacinth (Eichhornia crassipes) using the pyrolysis process, a thermochemical conversion technique. Water hyacinth, an invasive aquatic plant, poses significant environmental challenges, making it a viable feedstock for renewable energy production. The biomass was subjected to pyrolysis at controlled temperatures to produce bio-oil, biochar, and syngas. The process parameters, such as temperature, heating rate, and residence time, were optimized to maximize bio-oil yield. The chemical composition and calorific value of the bio-oil were analyzed to assess its potential as a sustainable energy source. Results demonstrated that water hyacinth is a promising raw material for biofuel production, offering dual benefits of energy generation and environmental remediation. This research highlights the potential of pyrolysis as an eco-friendly approach to managing invasive species and addressing energy demands.

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Chapter 1

Introduction

1.1 Introduction

In recent years, the search for sustainable and eco-friendly energy alternatives has gained significant momentum due to the rapid depletion of fossil fuels and increasing environmental concerns. Among the various renewable energy sources, biofuels have emerged as promising candidates to reduce carbon emissions and dependency on non-renewable energy resources. One of the most effective methods for producing biofuel is pyrolysis**,** a thermochemical process that converts organic material into bio-oil, biochar, and syngas in the absence of oxygen.

This thesis explores the production of biofuel from water hyacinth (Eichhornia crassipes)—an invasive aquatic weed that poses serious environmental and ecological challenges in water bodies across tropical and subtropical regions. While water hyacinth is often regarded as a nuisance due to its rapid spread and blockage of waterways, it is rich in lignocellulosic biomass, making it a suitable candidate for bio-energy production.

Among the different biofuel production methods, pyrolysis—a thermochemical decomposition process carried out in the absence of oxygen—is gaining attention for its ability to convert biomass into valuable products like bio-oil, biochar, and syngas. This thesis explores the feasibility and efficiency of producing biofuel from water hyacinth using the pyrolysis process.

1.2 Objectives

I. To design and implement a pyrolysis process suitable for converting water hyacinth into bio-oil.
II. To analyze the performance of fabricated biofuel.

1.3: Motivation

Bangladesh and many other tropical countries are plagued by water hyacinth, which grows rapidly in water bodies, obstructs waterways, depletes oxygen in water, and affects aquatic life and agriculture. While usually considered a waste, water hyacinth contains significant amounts of cellulose, hemicellulose, and lignin—key components of biomass suitable for pyrolysis. This inspired the idea of turning an environmental nuisance into a resource for clean energy. Moreover, with rising fuel prices and increasing environmental regulations, the development of biofuel from local, renewable, and waste resources like water hyacinth is a compelling and sustainable alternative.

1.4: Importance of biofuel

Biofuel plays a crucial role in ensuring energy security and reducing dependence on fossil fuels. It is renewable, biodegradable, and significantly less polluting than traditional fuels. In the context of climate change, biofuels contribute to reducing greenhouse gas emissions. They also promote rural development by creating job opportunities in biomass collection and processing. For developing countries, biofuel offers an opportunity to utilize local resources to meet energy demands in a sustainable manner.

1. Environmental Benefits:

Reduced Greenhouse Gas Emissions:

Biofuels can have lower greenhouse gas emissions than fossil fuels, especially when using advanced biofuel technologies and sustainable land management practices.

Clean Burning:

Biofuels produce fewer air pollutants than petroleum-based fuels, improving air quality.

Renewable and Sustainable:

Biofuels are produced from renewable resources like biomass and algae, unlike finite fossil fuels.

Reduced Reliance on Fossil Fuels:

By utilizing domestic biofuel production, countries can decrease their dependence on imported fossil fuels, enhancing energy security.

2. Economic Benefits:

Stimulating Rural Development:

Biofuel production can create new markets for agricultural products, boosting incomes for farmers and promoting rural economic growth.

Job Creation:

Biofuel production and processing can lead to new job opportunities in rural areas.

Energy Independence:

Local biofuel production can help reduce dependence on foreign oil, strengthening energy independence and stability.

3. Energy Security:

Reduced Geopolitical Vulnerability:

By diversifying energy sources and reducing reliance on volatile regions, biofuels contribute to energy security and stability.

Energy Independence:

Biofuel production can enhance a nation's energy independence by utilizing locally available resources.

Sustainable Energy Supply:

Biofuels offer a sustainable and renewable energy source that can help meet growing energy demands.

4. Technological Advancements:

Advanced Biofuel Technologies:

Research and development in advanced biofuel technologies are continuously improving efficiency and reducing costs.

Integration with Existing Infrastructure:

Biofuels can be used in existing vehicles and infrastructure, making them a practical option for transitioning to renewable energy.

Next-Generation Biofuels:

Biofuels made from wastes, cellulosic biomass, and algae-based resources are being developed for greater sustainability and efficiency.

1.5 Advantages:

1. **Renewable and sustainable**: Biofuel derived from biomass is continually replenishable and does not deplete natural resources.
2. **Environmental benefits**: Produces fewer emissions compared to fossil fuels and helps reduce greenhouse gases.
3. **Waste management**: Utilizes unwanted biomass like water hyacinth, reducing environmental hazards.
4. **Energy security**: Reduces reliance on imported fuels and enhances local energy independence.
5. **Economic development**: Encourages new industries, supports rural economies, and creates employment opportunities.

Chapter 2

Literature Review

2.1 Literature Review

1. Water Hyacinth as a Biomass Feedstock

Water hyacinth (*Eichhornia crassipes*) is an invasive aquatic weed known for its rapid growth and high cellulose, hemicellulose, and lignin content. It poses serious environmental problems by blocking waterways and depleting oxygen in water bodies. However, its high biomass yield and wide availability make it a promising feedstock for biofuel production. The average cellulose content in water hyacinth is around 20–35%, making it suitable for thermochemical conversion processes.

2. Pyrolysis as a Biofuel Production Method

Pyrolysis is a thermochemical decomposition process that occurs in the absence of oxygen, typically between 300°C and 600°C. It converts biomass into three main products:

1. Bio-oil (liquid fuel)
2. Biochar (carbon-rich solid)
3. Syngas (gaseous fuel)

Studies such as that fast pyrolysis is more effective in maximizing bio-oil yield, whereas slow pyrolysis produces more biochar. Parameters like temperature, heating rate, particle size, and residence time significantly influence product distribution.

3. Previous Research on Water Hyacinth Pyrolysis

Several studies have investigated the pyrolysis of water hyacinth:

1. Zhang et al. (2016) conducted pyrolysis at different temperatures and found the optimal bio-oil yield at around 500°C.
2. Akubo et al. (2019) compared the pyrolysis of water hyacinth with other aquatic plants and concluded that water hyacinth produces a good-quality bio-oil with moderate energy content (~20 MJ/kg).
3. Singh & Patil (2020) focused on the effect of particle size and found that smaller particles improve heat transfer and increase oil yield.

These findings highlight water hyacinth's viability as a low-cost, sustainable biomass source for pyrolysis.

4. Characterization of Bio-Oil

The bio-oil derived from water hyacinth typically contains oxygenated compounds such as acids, ketones, phenols, and aldehydes. Though it has a high oxygen content (20–40%), upgrading techniques like catalytic cracking or hydrodeoxygenation can improve its stability and energy density. GC-MS and FTIR analyses are commonly used to identify the chemical composition of bio-oil.

5. Environmental and Economic Benefits

Using water hyacinth for biofuel production has dual benefits: managing an invasive species and generating renewable energy. It reduces the dependency on fossil fuels, mitigates GHG emissions, and offers a cost-effective solution for biomass conversion, especially in regions where water hyacinth is abundant.

6. Research Gaps

While many studies highlight the potential of water hyacinth pyrolysis, further research is needed in:

1. Optimization of pyrolysis conditions for maximum yield and quality.
2. Life-cycle assessment of the entire process
3. Commercial scalability and techno-economic analysis.
4. Integration with upgrading technologies for refined biofuel.

2.2 Sustainable Biofuel from Water Hyacinth via Pyrolysis:

Pyrolysis, a thermochemical decomposition process in the absence of oxygen, is a preferred technique for converting biomass into liquid bio-oil, gas, and char. This method is advantageous for its potential to produce transportable liquid fuels and valuable chemicals. The paper explores the optimization of pyrolysis parameters—such as temperature, biomass particle size, and nitrogen gas flow rate—to maximize bio-oil yield from water hyacinth using a fixed-bed reactor.

The study found that the optimal conditions for maximum bio-oil yield (44.5 wt%) were 450 °C reactor temperature, 0.6 mm particle size, and 100 cm^3/min nitrogen flow. GC-MS analysis of the pyrolytic bio-oil revealed a diverse composition of compounds including phenols, alcohols, carboxylic acids, ketones, alkenes, alkanes, aldehydes, and aromatics, suggesting its potential as a renewable source of fuels and chemicals. [1]

The findings support the viability of water hyacinth pyrolysis as a sustainable energy solution and a method for managing the ecological threat posed by this invasive species.

2.3 Thermochemical Characterization of water hyacinth:

Water hyacinth (*Eichhornia crassipes*) has been identified as a promising feedstock for biofuel production due to its rapid growth, high productivity, and status as an invasive aquatic plant. Its conversion into bioenergy addresses both environmental and energy challenges. Huang et al. (2020) conducted a comprehensive study to explore the pyrolysis potential of water hyacinth, analyzing different biomass parts—roots (WHR), and stems and leaves (WHSL)—using thermogravimetric analysis (TGA), Fourier transform infrared spectroscopy (FTIR), and pyrolysis gas chromatography/mass spectrometry (Py-GC/MS). [8]

Key findings from their study include:

Pyrolysis Stages: The process occurs in three stages: moisture removal, devolatilization, and residual decomposition, within a temperature range of 200–600 °C.

Performance Comparison: WHSL showed superior pyrolysis performance compared to WHR, with lower activation energy (172.09–173.09 kJ/mol for WHSL vs. 230.11–232.06 kJ/mol for WHR), indicating easier thermal decomposition.

Heating Rate Effects: Higher heating rates increased peak temperatures and reduced reaction time, enhancing thermal conversion efficiency

Gas Emissions: The major gaseous products evolved were CO_2, C=O, C–O, SO_2, C=C, H_2O, CH_4, and CO, which provide insight into emission profiles and environmental considerations.

By-products: WHR produced significant amounts of phenols (19.2%) and furans (12.4%), while WHSL yielded nitrides (11.9%) and phenols (10%). These value-added chemicals have industrial potential. [8]

2.4 Evaluation of Aquatic Biomass Potential for Bio-Oil Production via Pyrolysis: A Focus on Water Hyacinth: [2]

1. Purpose of Study:

To investigate how different aquatic biomass types (Azolla, Sargassum tenerrimum, and Water Hyacinth) behave under slow pyrolysis in a fixed-bed reactor.To determine the effect of composition on product yields (bio-oil, bio-char, and gas).

2. Process Overview:

Slow pyrolysis conducted between 300–450°C under nitrogen (inert) atmosphere.Water hyacinth produced its maximum bio-oil yield (24.6 wt.%) at 400°C.

3. Bio-Oil Composition:

Analyzed using ^{1}H-NMR, FT-IR, and XRD techniques.Bio-oil from water hyacinth showed a high percentage of aliphatic functional groups, along with phenolics, ketones, and nitrogen-containing compounds.These features suggest bio-oil is potentially useful as a fuel or for chemicals.

4. Advantages of Aquatic Biomass:

Does not compete for arable land (unlike terrestrial biomass). Exhibits faster growth and higher photosynthetic efficiency.Water hyacinth is particularly abundant and problematic in many regions, making it an ideal low-cost, sustainable feedstock.

5. Significance of Pyrolysis:

Considered an effective thermochemical method to convert biomass to bio-oil, bio-char, and gases. Compared to combustion or gasification, pyrolysis provides better liquid fuel yields.

6. Comparison to Other Studies:

Similar studies on algae and duckweed showed comparable yields. However, aquatic biomass bio-oil tends to contain higher nitrogen content, which must be addressed for fuel applications. [2]

2.5 Biomass and Renewable Energy

Biomass represents a carbon-neutral, renewable energy resource with significant potential to replace fossil fuels. As noted by Demirbas (2001), biomass can be utilized for both heat and power generation, offering a cleaner and more sustainable energy alternative. Lignocellulosic biomass—derived from plant cell wall materials—is especially attractive because it does not interfere with food supply chains and is available globally. [11]

2.6 Water Hyacinth as a Biomass Source

Water hyacinth is one of the fastest-growing aquatic plants, with a doubling time of 5 to 15 days under optimal conditions (Gunnarsson & Petersen, 2007). It has an energy value of approximately 14–18 MJ/kg, depending on the degree of drying and treatment. Despite its high water content (~90%), the plant's rapid growth and nutrient absorption capacities make it ideal for bioenergy applications, especially when integrated with pre-treatment or hybrid energy systems. [12]

2.7: Bio-Oil Yield Optimization from Water Hyacinth via Catalytic Pyrolysis Using Waste Cu and Al Catalysts

The present study investigates the viability of producing biofuel from *Eichhornia crassipes* (water hyacinth) using pyrolysis, a thermochemical decomposition process

conducted in the absence of oxygen. Water hyacinth, an invasive aquatic plant commonly regarded as a nuisance, is redefined in this research as a valuable biomass resource due to its rapid growth, high availability, and lignocellulosic composition.

The literature supports pyrolysis as an efficient pathway for converting biomass into three primary products: bio-oil, bio-char, and syngas. These products can serve as substitutes or supplements to fossil fuels. This study builds upon previous findings by optimizing process variables such as temperature (150–450°C), heating rate, biomass and catalyst particle size, and reaction duration to maximize bio-oil yield and calorific value.

Catalytic pyrolysis using waste Cu and Al particles, compared with non-catalytic processes, was central to the analysis. Literature indicates that catalysts influence both product yield and chemical composition. In this study, Cu catalysts significantly enhanced the production of aliphatic hydrocarbons in the bio-oil, while Al catalysts favored aromatic hydrocarbons, leading to a higher calorific value. Optimal yields were achieved at 450°C, 60 minutes, and with fine biomass and catalyst particle sizes. [5]

Analytical techniques such as GC–MS and FT-IR confirmed that bio-oil composition varies with catalyst type, aligning with earlier studies on selective hydrocarbon formation. The findings confirm prior research on the role of temperature, reaction time, and catalyst surface area in influencing pyrolytic product distributions.

This study contributes to the body of knowledge by:

1. Demonstrating effective utilization of water hyacinth for energy recovery.
2. Validating waste-derived catalysts (Cu and Al) as cost-effective agents for pyrolysis.
3. Enhancing understanding of catalyst-specific hydrocarbon formation pathways.
4. Providing a sustainable solution to water hyacinth overgrowth and fossil fuel dependence.

2.8 Thermochemical Conversion Techniques

Among the different biomass conversion technologies—combustion, gasification, and pyrolysis—pyrolysis is particularly suitable for producing liquid bio-fuels. Pyrolysis typically occurs between **350°C** and **550°C** and can be conducted in different modes: slow, fast, and flash pyrolysis, depending on the heating rate and residence time (Bridgwater, 2003). [13]

2.9 Pyrolysis of Water Hyacinth

Recent studies have explored pyrolysis of water hyacinth to derive bio-fuels. Fahmi et al. (2013) reported that pyrolyzing water hyacinth at 450°C yields approximately 45% bio-oil, 35% bio-char, and 20% syngas. The quality and distribution of products vary based on temperature, particle size, and heating rate (Zabaniotou & Ioannidou, 2008). The calorific value of the bio-oil ranges between 18–25 MJ/kg, and it typically includes organic compounds such as phenols, ketones, and furans. [14]

2.10: Transforming an Ecological Menace into a Green Energy Asset: The Case of Water Hyacinth

Water hyacinth (*Eichhornia crassipes*), once valued as an ornamental plant, has become one of the world's most aggressive aquatic weeds due to its rapid growth and adaptability. However, recent research, including that of Bhattacharya and Kumar (2010), highlights its emerging value as a promising biofuel crop, especially for developing countries facing energy shortages and environmental concerns.

The plant possesses key attributes desirable for biofuel production: high growth rate, minimal nutrient needs, and notably low lignin content (~10%) with high cellulose and hemicellulose content (25% and 35% respectively). These features make it easier to convert into fermentable sugars for ethanol production with lower energy and enzyme input compared to other lignocellulosic biomasses. [7]

The study underscores various bioenergy potentials of water hyacinth:

1. **Bioethanol and Biobutanol:** Fermentation of cellulose and hemicellulose using engineered or native microbes.
2. **Biogas and Biohydrogen:** Anaerobic digestion for methane and hydrogen production.
3. **Biomethanol:** Produced via gasification and condensation under high pressure.
4. **Organic fertilizer and compost:** Due to its high ash and nutrient content.
5. **Environmental applications:** Phytoremediation of heavy metals, wastewater treatment, and erosion control.

Additionally, the paper discusses the scope for genetic engineering to further enhance biofuel yield through manipulation of lignin biosynthesis pathways and cellulase production. Tissue culture techniques and transgenic approaches are also explored for optimizing biomass characteristics and simplifying processing. [7]

The authors advocate for a paradigm shift—viewing water hyacinth not just as an ecological threat but as a renewable, low-input resource with high energy potential and multiple co-benefits, including rural employment, waste management, and energy security.

2.11 Bio-Oil Characteristics and Upgrading

Crude bio-oil is typically acidic (pH 2.5–4.5), viscous, and rich in oxygenated compounds, which limits its direct use in engines. However, various upgrading processes such as hydrodeoxygenation, catalytic cracking, and emulsification can improve its quality for use as a transport fuel (Oasmaa & Czernik, 1999). [15]

2.12 Bio-Char and Syngas Applications

Bio-char is a carbon-rich solid residue that improves soil fertility, retains water, and acts as a carbon sink, making it valuable for sustainable agriculture (Lehmann et al., 2006). Syngas, a mixture of carbon monoxide (CO), hydrogen (H_2), and methane (CH_4), can be combusted directly for power or serve as a precursor for synthetic fuels and chemicals. [16]

2.13 Environmental and Economic Considerations

The utilization of water hyacinth in bio-fuel production offers dual environmental benefits: it mitigates the adverse effects of this invasive species on aquatic ecosystems while contributing to renewable energy generation. It supports circular economy principles and creates potential for local job generation in rural communities. However, the economic feasibility of pyrolysis depends on key factors such as biomass drying efficiency, reactor design, and upgrading infrastructure. [17]

2.14 Contribution of Water Hyacinth to Material Science and Bio-Fuel Research

According to Saha (2011), water hyacinth contains substantial amounts of cellulose and hemicellulose, making it suitable for conversion through thermochemical processes like pyrolysis. His research at BUET focused on utilizing water hyacinth fibers in polypropylene composites, confirming the plant's mechanical strength and thermal stability. Although the study primarily aimed at material reinforcement, the findings also support the feasibility of water hyacinth as a biomass feedstock for the production of bio-oil and bio-char through pyrolysis. [18]

Chapter 3

Material and Instrument

3.1 Material:

In this study, two primary materials were utilized: water hyacinth (Eichhornia crassipes) and iron (III) chloride ($FeCl_3$)**.** These materials were selected due to their effectiveness in wastewater treatment applications and their potential for environmental sustainability.

1. Water Hyacinth (Eichhornia crassipes)

Water hyacinth, a free-floating aquatic plant, was collected from [Shondra river, uzirpur, Barishal]. The plant was chosen for its high availability, rapid growth, and proven capacity to absorb heavy metals and other contaminants from aqueous solutions. Prior to use, the collected water hyacinths were thoroughly washed with distilled water to remove debris. The roots and stems were then separated, dried under sunlight for several days to remove moisture content. After drying, the material was ground into a fine powder using a mechanical grinder and stored in airtight containers for further use.



Figure-3.1**:** The Water hyacinth (Eichhornia crassipes).

2. Iron (III) Chloride ($FeCl_3$)

Iron (III) chloride, also known as ferric chloride, was used as a chemical coagulant in the treatment process. The reagent-grade $FeCl_3$ (purity ≥ 98%) was purchased from [Science Market, 34/A Hatkhola Road, Dhaka 1203]. We have been used Iron (III) Chloride ($FeCl_3$) 162 g or 0.162 kg for making solution to dissolve the sample into the solution. It was used in the preparation of coagulant solutions for experimental purposes. $FeCl_3$ was chosen due to its strong coagulating properties, its ability to destabilize and aggregate suspended particles, and its effectiveness in reducing turbidity and other pollutants from water.

.



Figure-3.2**:** Iron (III) Chloride ($FeCl_3$)

Supporting Materials

1. **Distilled Water:** Used for washing and preparing solutions (1 liter of crystal water).
2. **Glassware:** Beakers, measuring cylinders, and flasks were used throughout the preparation and experimental procedures.
3. **Oven:** Used to dry the water hyacinth samples at controlled temperature.
4. **Mechanical Grinder:** For converting the dried plant material into powder form.

3.2 Instruments:

A variety of instruments and laboratory tools were employed throughout the experimental procedures to ensure safety, accuracy, and proper handling of materials. Each instrument played a vital role in the preparation, filtration, treatment, and analysis stages of the study.

1. Hand Gloves

Laboratory-grade hand gloves (nitrile or latex) were used throughout the experimental process to ensure safety and prevent direct contact with chemicals such as iron (III) chloride. Wearing gloves also helped maintain the sterility of the samples and avoid cross-contamination during handling and preparation. It was purchased from [Science Market, 34/A Hatkhola Road, Dhaka 1203], Quantity 02 Pair.



Figure 3.3: Hand gloves.

2. Chemical Jars:

Chemical jars made of borosilicate glass were used for storing and preparing chemical solution, including $FeCl_3$. These jars are resistant to thermal shock and corrosion, making them suitable for holding strong chemical solution without altering their

properties. These were purchased from [Science Market, 34/A Hatkhola Road, Dhaka 1203]



Figure 3.4: Chemical jars**.**

3. Filters

Filtration units and filter papers were used to separate solid residues (such as undissolved plant material or suspended particles) from the treated water samples. The filters ensured clarity and precision in the final analysis by removing unwanted particulates after treatment. It was purchased from [Science Market, 34/A Hatkhola Road, Dhaka 1203].



Figure-3.5: Filter

4. Stirring Rod

Plastic or glass stirring rod were used to mix solution and help in the uniform dispersion of coagulants in the water during the treatment process. Proper mixing is essential for the effectiveness of coagulation and adsorption. It was purchased from [Science Market, 34/A Hatkhola Road, Dhaka 1203].



Figure-3.6**:** Stirring Rod.

5. Pots and Containers

Various plastic and metal pots were used to hold water samples during the treatment process. These containers were chosen based on their non-reactive nature and capacity to handle different volumes of liquid safely. They served as reaction vessels where the actual water purification process took place using hyacinth powder and iron chloride. These were purchased from [Science Market, 34/A Hatkhola Road, Dhaka 1203]



Figure-3.7**:** Containers.

6. Measuring Cylinders and Beakers

Measuring cylinders (50 ml – 1000 ml) and glass beakers were used for precise measurement of water, chemical reagents, and other solutions. Accurate measurement was crucial for maintaining consistent experimental conditions and reproducibility. It was purchased from [Science Market, 34/A Hatkhola Road, Dhaka 1203].



Figure-3.8**:** Measuring Cylinder.

7. Oven (for drying)

An electric drying oven was used to remove moisture from the water hyacinth samples. The oven maintained a constant temperature of 60°C for even and controlled drying, which is essential to preserve the plant's adsorption capacity. We have been used electric heater or oven from our mechanical lab.



Figure-3.9**:** Electric Heater.

8. Weighing Scale

A digital electronic balance with a precision of up to 0.01 grams was used to measure the exact quantity of hyacinth powder and iron chloride. This ensured the reliability of data by maintaining accurate dosages during the treatment process.The balance machine we have used from our mechanical lab.

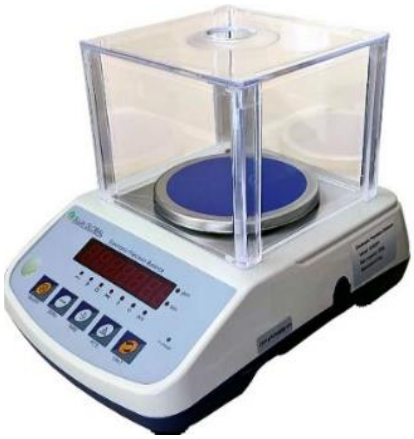


Figure-3.10: Weighing Scale.



Figure 3.11: All instruments together.

Chapter 4

Methodology

In this research, water hyacinth (*Eichhornia crassipes*) was utilized as the primary biomass feedstock for the preparation of biochar. The following steps were conducted systematically to prepare the sample and analyze its characteristics:

4.1: Collection and Pre-treatment of Biomass

Water hyacinth plants were collected from Shondra river, uzirpur, Barishal. The collected plants were thoroughly washed with distilled water to remove soil, dust, and other impurities adhering to the surface. Then we took the measurement of collected water hyacinth. In wet condition the collected water hyacinth was 1000 gm or 1 kg. After that, the water hyacinth was left to dry under direct sunlight for several days until all moisture content was visibly eliminated. This natural drying process ensured that the initial water content was reduced before further processing. After the drying process the water hyacinth weight was 127 gm or 0.127 kg. Now we can identify the moisture content of water hyacinth.

Wet hyacinth = 1000 gm
Dry hyacinth = 127 gm
Moisture content= (1000 – 127) gm = 873 gm.

We can see into 1000 gm of water hyacinth the moisture content is 873 gm.



Figure 4.1: The drying process of water hyacinth through sunlight.

4.2: Grinding and Size Reduction

Once the biomass was completely dried, it was mechanically ground using a grinding machine to achieve a fine powder form. This step was essential to increase the surface area of the material, facilitating uniform heating during biochar production and improving the efficiency of the chemical interaction during activation. Before using the grinding machine, we have been cut the dry water hyacinth into a very small pieces. Then small pieces of water hyacinth insert into grinding machine and stat the grinding process. After grinding all hyacinths did not become powder so we needed to filter those samples to get original powder sample. After completing those process, we got our desire sample.



Figure 4.2: Grinding and filtering the water hyacinth

4.3: Preparation of Iron Chloride Solution

To activate the biomass chemically, a solution of iron(III) chloride ($FeCl_3$) was prepared in distilled water. The ground water hyacinth powder was then dissolved into this iron chloride solution under constant stirring. For making the solution at first we have toke 1 M of iron(III) chloride ($FeCl_3$) with 1 L of crystal water .But there have no fixed amount of water for 1 M of iron(III) chloride ($FeCl_3$).

We know,

1 M ($FeCl_3$) = 162 gm ($FeCl_3$)

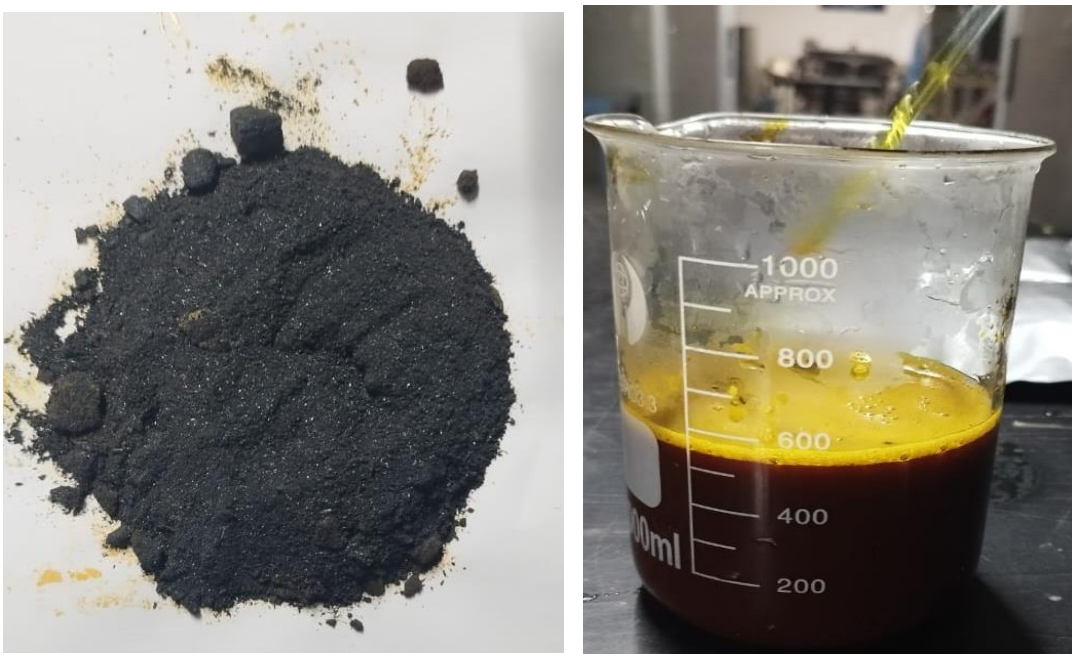


Figure 4.3: 1 M $FeCl_3$ and solution

4.4: Preparation of bio-char

Biochar is a carbon-rich, charcoal-like substance that is produced by heating organic material (biomass) such as plant waste, agricultural residues, or wood in a low-oxygen environment. This process is called pyrolysis.

Water hyacinth (Eichhornia crassipes) is a fast-growing aquatic plant known for clogging rivers and lakes. Though invasive, it has high cellulose, hemicellulose, and lignin content, making it an excellent biomass feedstock for biochar production.

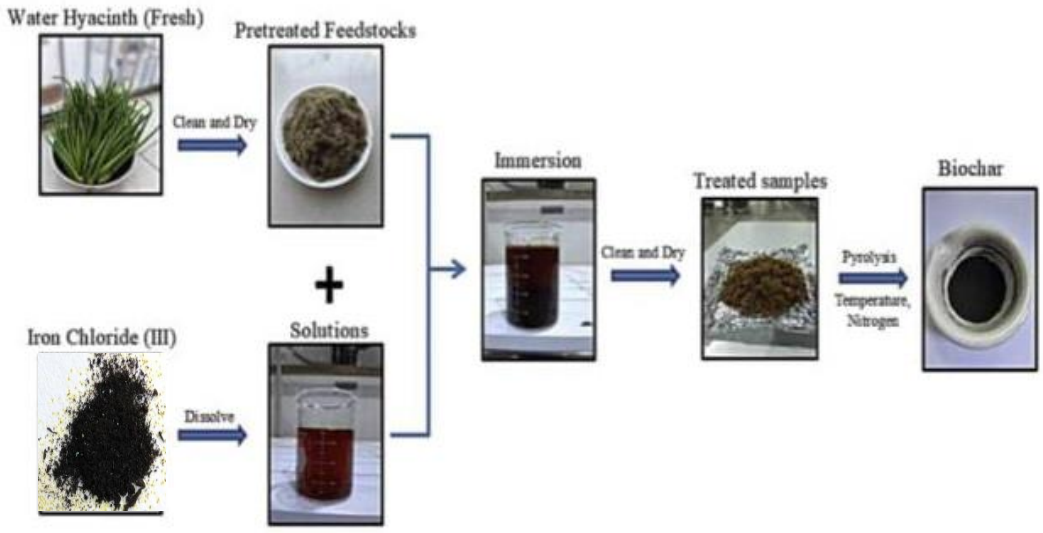


Figure 4.4: The preparation of modified feedstock composite (biochar/γ-Fe_2O_3)

📌 **Step-by-Step Process:**

1. **Collection of Raw Material:**

   Fresh Water Hyacinth is collected as the main biomass feedstock.

2. **Cleaning and Drying:**

   The water hyacinth is cleaned to remove impurities and then dried to reduce moisture content.

3. **Pretreatment**

   The dried hyacinth is ground or crushed into small pieces (pretreated feedstocks).

4. **Iron Solution Preparation**

   Iron(III) chloride ($FeCl_3$) is dissolved in water to form a ferrous solution.

5. **Immersion Process**

   The pretreated biomass is immersed in the iron chloride solution to allow impregnation of iron into the biomass.

6. **Drying of Treated Biomass**

   The impregnated feedstock is filtered, cleaned, and dried again to remove excess moisture and chemicals.

7. **Pyrolysis (Carbonization)**

   The dried, treated sample is subjected to pyrolysis (heating in the absence of oxygen), under controlled temperature and nitrogen gas flow. This converts the biomass into biochar and forms γ-Fe_2O_3 (maghemite**)** within the structure, resulting in magnetic biochar.

8. **Final Product**

   The final product is biochar/γ-Fe_2O_3, which can be used for various environmental or industrial applications like adsorption, catalysis, or pollutant removal.

4.5: Thermal Treatment (Carbonization)

The impregnated sample was transferred into our laboratory electric furnace (or electric heater) and subjected to thermal treatment at a temperature of 70°C for a duration of 10 hours. This low-temperature pyrolysis facilitated the slow carbonization of the biomass, resulting in the formation of biochar. During this process, volatile organic compounds were released, and the remaining solid structure became carbon-rich and porous.



Figure 4.5: Using an electric heater at 70°C temperature

4.6: Filtering the biochar:

Filtering the biochar sample is a crucial post-treatment step used to remove residual chemicals, unreacted minerals, and impurities after processes like chemical impregnation or pyrolysis—especially if the biochar is intended for environmental or agricultural use. After taking out the biochar sample from the electric heater, we keep it few moments on the table for being cold. Then we filtered it by local filter.



Figure 4.6: Filtering the biochar sample.

4.7: Post-treatment Drying

After the completion of carbonization, the biochar sample was again air-dried or oven-dried to remove any residual moisture or solvent. This ensured that the final product was in a stable, dry form, ready for characterization and testing.



Figure 4.7: Post drying the sample.

4.8: Sample Testing and Characterization

The final biochar sample was then sent for characterization using three advanced analytical techniques:



Figure 4.8: The final sample.

1. Scanning Electron Microscopy (SEM**):** Used to observe the surface morphology and pore structure of the biochar.
2. Energy-Dispersive X-ray Spectroscopy (EDS): Employed to determine the elemental composition and confirm the presence of iron or other significant elements on the biochar surface.
3. Fourier Transform Infrared Spectroscopy (FTIR): Conducted to identify the functional groups present in the biochar and to evaluate any chemical changes due to activation and carbonization.

Chapter-5

Result

5.1.1: The SEM (Scanning Electron Microscopy):

SEM testing is used to study the surface morphology, structure, and composition of materials at high magnifications. It provides detailed images by scanning a sample with a focused beam of electrons**.** The morphological characteristics of water hyacinth biochar prepared in different concentrations of ferric chloride hexa-hydrate were shown in figure .The presence of the large pores can be observed in the biochar sample with the appearance of microstructures on the surface of those treated feedstocks.

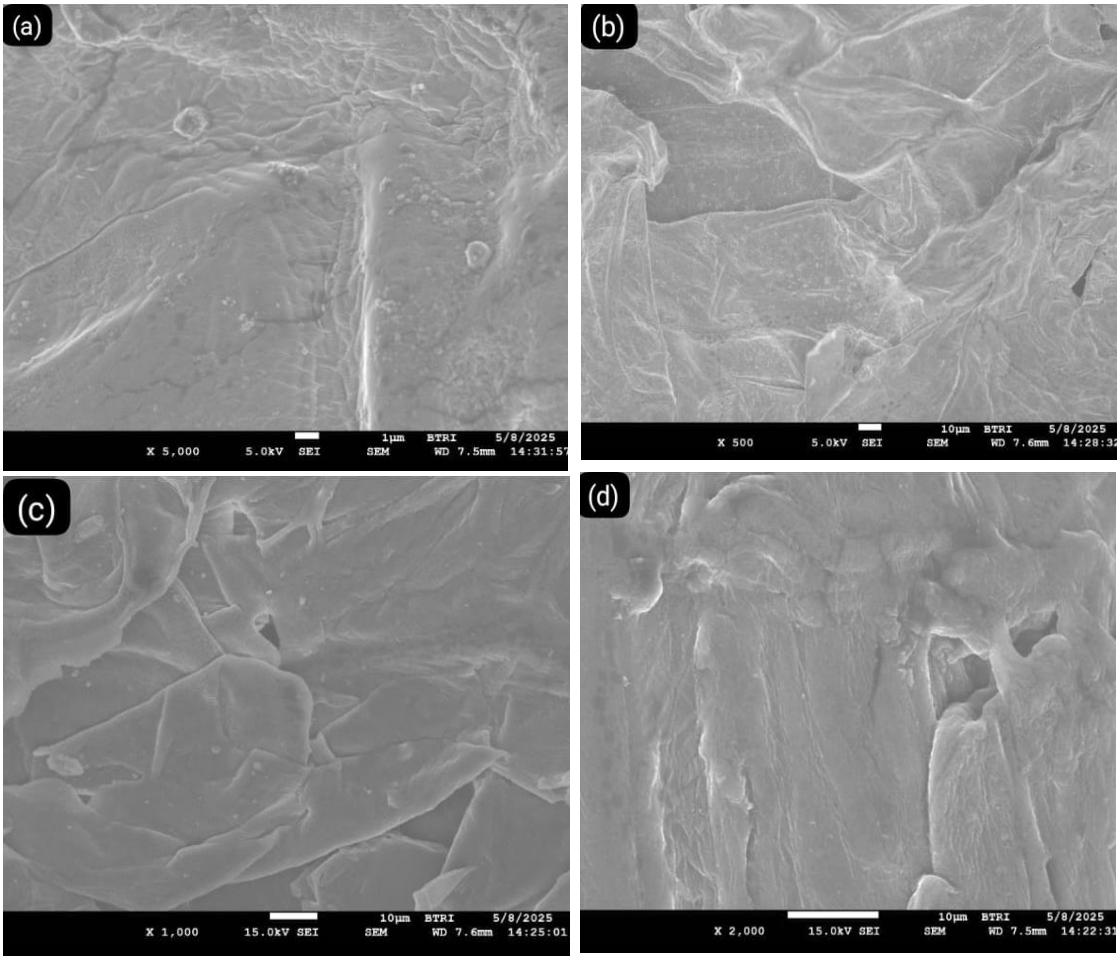


Figure 5.1: The SEM images of (a) x 5,000, 1 µm scale bar, (b) x 500, 1 µm scale bar, (c) x 1,000, 10 µm scale bar, (d) x 2,000, 10 µm scale bar.

5.1.2: Image (a)

This image appears to be a Scanning Electron Microscope (SEM**)** micrograph. Based on the scale and magnification details (x 5,000, 1 µm scale bar), here are key observations and explanations:

Observations:

1. **Magnification**: The image shows the surface of a sample at 5,000x magnification.
2. **Surface Features**: The texture is irregular, with noticeable ridges, grooves, and craters. The small circular and irregular features might indicate porosity, defects, or surface roughness.
3. **Material Type**: While the material isn't explicitly identified in this image, such surfaces are often analyzed for Coating uniformity. Cracks or fractures in materials. Surface morphology of biological, polymeric, or metallic samples.
4. **Accelerating Voltage**: The electron beam was operated at 5.0 kV, suggesting the focus was on surface details without penetrating too deeply into the material.

Possible Interpretations:

1. **Cracks and Defects**: The larger grooves and cracks may indicate mechanical stresses or imperfections in the sample.
2. **Pitting or Corrosion**: The circular features might represent pitting, indicative of corrosion in metallic samples.
3. **Surface Preparation**: Any observable unevenness could be due to improper sample preparation (e.g., polishing)

5.1.3: Image (b)

General Observations:

1. **Surface Morphology**:

   The micrograph reveals a wrinkled or layered texture, which mayindicate a thin film, layered material, or a composite structure.These features are consistent with materials like graphene oxide, carbon nanotubes, or other layered nanomaterials.

2. **Magnification and Features**:

   At 500x, the visible structures suggest surface irregularities or inter-layer voids, potentially resulting from synthesis, processing, or environmental interactions.

3. **Potential Material Type**:

   If this is part of a materials science study, the image might correspond to an analysis of surface properties, defects, or porosity in materials like polymers, coatings, or metallic films.

5.1.4: Image (c)

Magnification and Scale:

The image has a magnification of 1,000×.The scale bar indicates a length of 10 µm (micrometers), allowing for an understanding of the feature sizes.

Imaging Parameters:

Accelerating voltage: 15.0 kV, which is a common setting for SEM imaging to achieve good contrast and depth.Working distance: 7.6 mm, showing the distance between the sample and the SEM column.

Observations in the Microstructure:

The surface appears to have layered or flake-like structures.These features could indicate the material has a lamellar structure, which is typical in materials like graphene oxide, mica, or certain composites.No significant porosity or defects are evident at this magnification.

Material or Application:

If this is part of a study, the structure could relate to properties such as surface roughness, flake distribution, or mechanical strength.The absence of voids or cracks suggests a cohesive and possibly well-prepared material.

Test Context:

If this image represents a composite or coated material, the uniformity of layers may be relevant for applications like electronics, coatings, or reinforcement.

5.1.5: Image (d)

Observations:

1. **Magnification:** 2,000×
2. **Scale Bar:** 10 μm (indicating that the width of the white bar represents 10 micrometers).
3. **Voltage:** 15.0 kV (indicating the accelerating voltage of the SEM).

4. **Material Structure:** The surface seems to display a fibrous, layered, or fractured morphology.There are voids or cracks in certain areas, which might indicate defects or stress failure.

Interpretation:

1. **Material Identification:** This SEM image might represent a polymer, composite, or fractured surface of a brittle material.

2. **Cracks or Voids:** These could result from:Mechanical testing (e.g., tensile, compression, or impact).Structural failure or poor adhesion in composites.

3. **Layered Structure:** If this is a composite, it might show fiber pullout or delamination.

2.2.1 The EDS (Energy Dispersive X-ray Spectroscopy):

The EDS analysis (Figure) identified the primary elements present in the sample as carbon (C), oxygen (O), and iron (Fe).

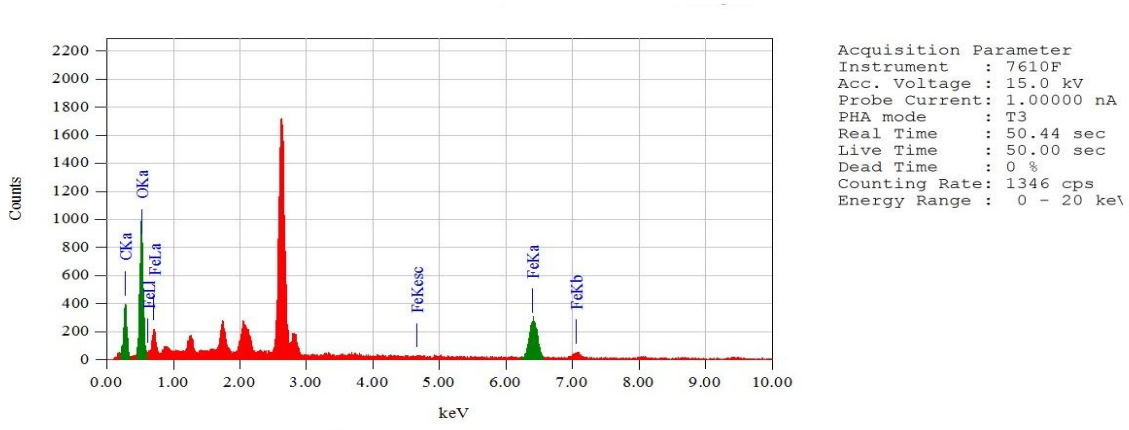


Figure 5.2: Energy Dispersive Spectroscopy spectra of magnetic biochar sample.

The EDS spectrum shows the elemental composition at the analyzed point. Here's the detailed breakdown:

Element	Peak Energy (keV	Mass %	Atom %	Comments
C (Carbon)	0.277 keV	24.14%	40.58%	Major organic element; part of cellulose, lignin, etc
O (Oxygen)	0.525 keV	35.55%	44.85%	Strong presence indicates cellulose, hemicellulose, water, etc.
Fe (Iron)	6.398 keV	40.31%	14.57%	High iron content—possibly due to external contamination, iron-based treatment, or mineral absorption

Total mass %: 100%, which is standard for EDS normalization

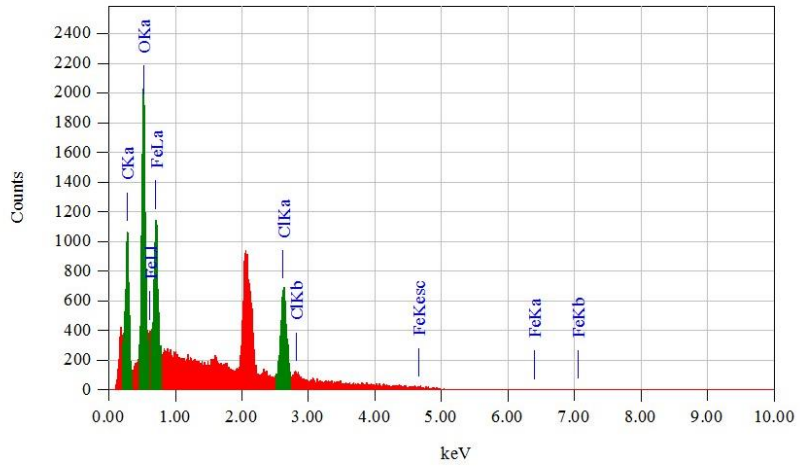
Key Takeaways:

1. The material is rich in carbon and oxygen, confirming organic plant-based composition (like cellulose).

2. Iron (Fe**)** is unexpectedly high. Possible reasons. The plant (hyacinth) absorbed iron from soil or water. Sample surface was contaminated or treated with iron. Environmental pollution led to Fe accumulation.

3. This result is common in phytoremediation studies, where plants absorb heavy metals from their surroundings.

5.2.2: EDS Spectrum and Quantitative Analysis:




```
Acquisition Parameter
Instrument   : 7610F
Acc. Voltage : 5.0 kV
Probe Current: 1.00000 nA
PHA mode     : T3
Real Time    : 50.58 sec
Live Time    : 50.00 sec
Dead Time    : 1 %
Counting Rate: 1933 cps
Energy Range :  0 - 20 keV
```

ZAF Method Standardless Quantitative Analysis
Fitting Coefficient : 0.1909

Element	(keV)	Mass%	Sigma	Atom%	Compound	Mass%	Cation	K
C K	0.277	10.73	0.07	25.30				5.8216
O K	0.525	14.62	0.12	25.89				16.1279
Cl K*	2.621	37.45	0.60	29.93				47.5026
Fe L	0.705	37.20	0.47	18.87				30.5478
Total		100.00		100.00				

Figure 5.3: Dispersive X-ray Spectroscopy (EDS/EDX) analysis.

EDS Spectrum and Quantitative Analysis (Lower Section):

1. **EDS Spectrum**:

   The spectrum shows peaks corresponding to characteristic X-ray energies emitted by elements in the sample. Peaks labeled (e.g., C Kα, O Kα, Fe Lα, Cl Kα) indicate the elements detected, along with their respective energy levels (keV). High counts at certain energy levels (e.g., 0.277 keV for C, 0.525 keV for O, 2.621 keV for Cl) correspond to the abundance of those elements.

2. **Quantitative Analysis Table**:

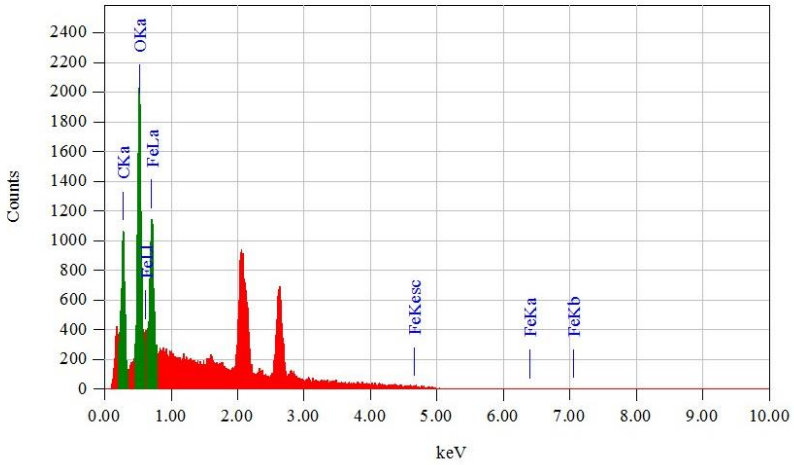
    a. Elements Detected: C (Carbon): 10.73% by mass. O (Oxygen): 14.62% by mass. Cl (Chlorine): 37.45% by mass. Fe (Iron): 37.20% by mass.
    b. Compound and Atom %: These represent the proportion of each element as part of the total mass and atomic count.
    c. Sigma: The standard deviation, showing the reliability of the measurements.

Key Observations:

1. The sample contains a significant amount of chlorine (Cl) and iron (Fe), suggesting it might be part of a material with chloride compounds or corrosion products (e.g., FeCl3 or Fe2O3/FeCl2).

2. The presence of carbon (C) and oxygen (O) could indicate organic contamination, oxide layers, or residual compounds on the sample surface.

5.2.3: EDS Spectrum (Graph and Table):




```
Acquisition Parameter
Instrument   : 7610F
Acc. Voltage : 5.0 kV
Probe Current: 1.00000 nA
PHA mode     : T3
Real Time    : 50.58 sec
Live Time    : 50.00 sec
Dead Time    : 1 %
Counting Rate: 1933 cps
Energy Range :  0 - 20 keV
```

```
ZAF Method Standardless Quantitative Analysis
Fitting Coefficient : 0.3588
Element        (keV)   Mass%   Sigma   Atom%  Compound   Mass%  Cation        K
 C K           0.277   10.86    0.07   25.80                              11.0894
 O K           0.525   22.49    0.19   40.13                              30.7214
Fe L           0.705   66.65    0.84   34.07                              58.1892
Total                 100.00          100.00
```

Figure 5.4: The elemental composition of the sample**.**

EDS analysis provides the elemental composition of the sample. The spectrum plots intensity (Counts) versus energy (keV), where peaks correspond to specific elements.

Key Observations from EDS Spectrum:

1. **Major Peaks**:

   C K (Carbon) Low-energy peak, indicative of organic material or carbon-based compounds in the sample. O K (Oxygen) A prominent peak, suggesting oxides or oxygen-bound compounds. Fe L (Iron**)** A significant peak, indicating the presence of iron, likely as part of an oxide or alloy.

2. **Quantitative Data (Table Below the Spectrum)**:

   a. **Elements Detected**: Carbon (C), Oxygen (O), and Iron (Fe).

   b. **Mass%**: Carbon (C) ~10.86%, Oxygen (O) ~22.49%, Iron (Fe) ~66.65%

   c. **Atom%**: Indicates relative atomic abundance, showing more oxygen compared to carbon and iron due to the lower atomic mass of oxygen.

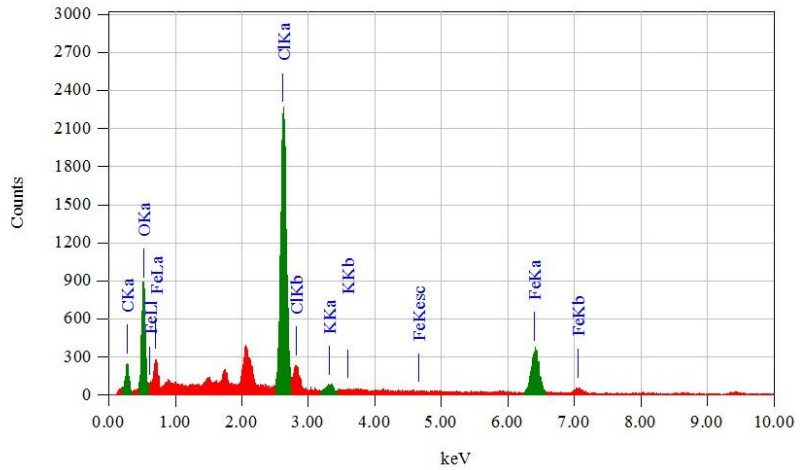
ZAF Correction:

This analysis uses the ZAF method (atomic number, absorption, and fluorescence) to correct for physical factors affecting the X-ray signal.

Acquisition Parameters (Right Column)

a. Instrument: JEOL 7610F SEM.
b. Accelerating Voltage: 5.00 kV.
c. Probe Current: 1.00000 nA.
d. Acquisition Time: ~50 seconds

5.2.4: EDS Spectrum:




```
Acquisition Parameter
Instrument    : 7610F
Acc. Voltage : 15.0 kV
Probe Current: 1.00000 nA
PHA mode      : T3
Real Time     : 50.53 sec
Live Time     : 50.00 sec
Dead Time     : 1 %
Counting Rate: 1605 cps
Energy Range :  0 - 20 keV
```

ZAF Method Standardless Quantitative Analysis
Fitting Coefficient : 0.0736

Element	(keV)	Mass%	Sigma	Atom%	Compound	Mass%	Cation	K
C K	0.277	23.59	0.35	41.19				4.3578
O K	0.525	26.24	0.34	34.40				22.2307
Cl K*	2.621	25.08	0.21	14.84				39.5349
K K*	3.312	0.92	0.06	0.49				1.3264
Fe K	6.398	24.18	0.44	9.08				32.5503
Total		100.00		100.00				

Figure 5.5: The Energy Dispersive X-ray Spectrum.

EDS Spectrum:

The graph below the SEM image is the Energy Dispersive X-ray Spectrum, showing peaks for different elements detected in the sample. X-axis Energy levels in keV. Y-axis Counts, representing the intensity of X-rays detected for each energy level. Each labeled peak (e.g., C Kα, O Kα, Cl Kα, Fe Kα) corresponds to a specific element and its characteristic X-ray energy.

Quantitative Elemental Analysis (Table at Bottom):

This section shows the quantitative results of the EDS analysis. Key columns:

1. Element: Elements identified in the sample (e.g., Carbon (C), Oxygen (O), Chlorine (Cl), Potassium (K), Iron (Fe)).

2. Mass%: Percentage by weight of each element in the sample.
3. Atom%: Percentage by number of atoms for each element.
4. Compound Mass%: Estimated percentage of the element in combined compounds.
5. Cation K: Calculated ionic contribution of each element.

Interpretation:

1. The main elements in the sample are Carbon (C), Oxygen (O), Chlorine (Cl), Potassium (K), and Iron (Fe).
2. The Mass% distribution suggests. The sample contains significant amounts of oxygen (26.24%) and chlorine (25.08%), possibly from compounds such as chlorides or oxides. Carbon (23.59%) may come from organic material or carbon-based compounds. Iron (24.18%) and potassium (0.92%) suggest the presence of minerals or metallic oxides.

Acquisition Parameters (Right Side):

a. Instrument: JEOL 7610F SEM.
b. Voltage: Accelerating voltage of 15.0 kV.
c. Probe Current: Electron beam current of 1.00 nA.
d. Energy Range: 0–20 keV.
e. Counting Rate: 1605 counts per second, indicating good signal strength.

5.3 The FTIR (Fourier Transform Infrared Spectroscopy):

FTIR spectroscopy is a powerful analytical technique used to identify and characterize chemical compounds by analyzing their unique vibrational frequencies in the infrared region of the electromagnetic spectrum. It works by shining infrared light through a sample and detecting the wavelengths that are absorbed. The resulting spectrum, a plot

of absorbance versus wavenumber, reveals information about the functional groups present in the sample. This information is crucial for identifying unknown materials, confirming the composition of known materials, and studying the structure and reactions of molecules**.**

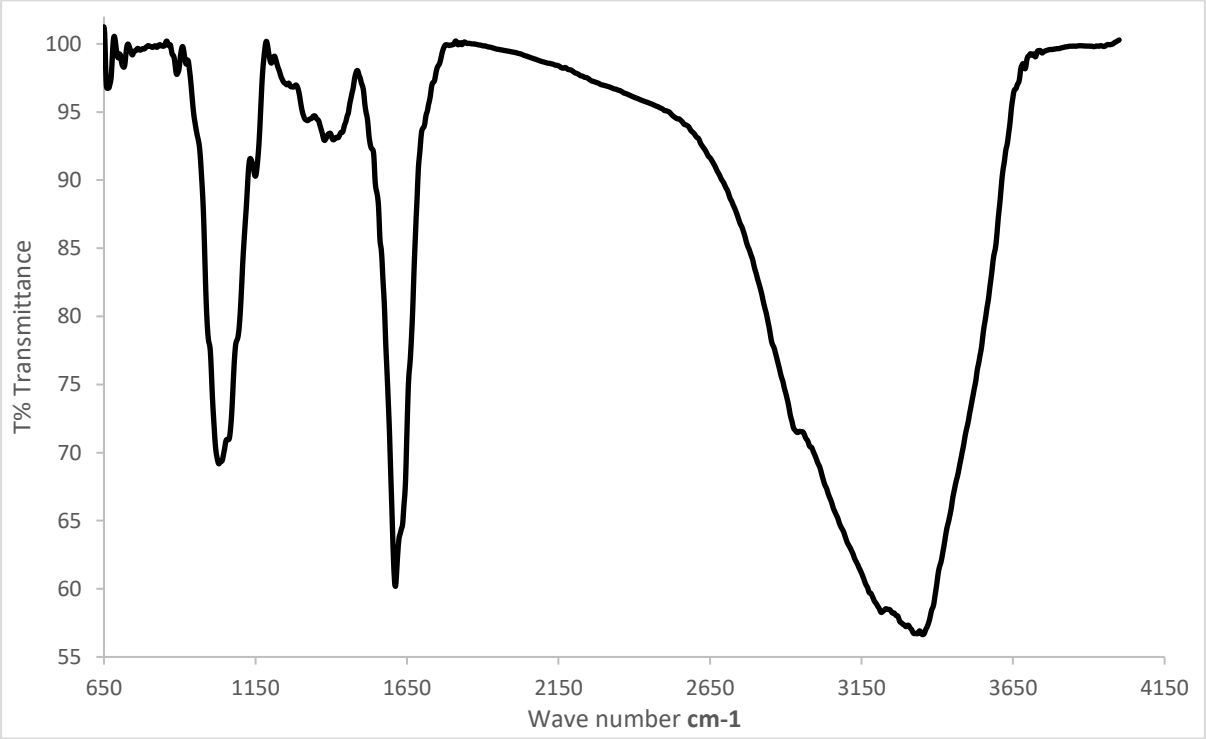


Figure 5.6: FTIR spectroscopic analysis of sample.

This is an FTIR (Fourier Transform Infrared) spectrum graph, typically used to identify the functional groups and molecular structure of a sample. Here's how to interpret it:

Key Components of the Graph:

1. X-axis (Wave Number, cm^{-1}):

   Represents the infrared frequencies (wave numbers) absorbed by the sample. Each wave number corresponds to a specific vibrational mode of bonds in the sample.

2. Y-axis (% Transmittance):

   Shows how much infrared radiation passes through the sample. Lower transmittance (dips in the graph) indicates strong absorption at that frequency, corresponding to specific molecular vibrations.

Peaks and Their Possible Interpretations:

1. Around 650–1150 cm^{-1}: Typically associated with C–H bending vibrations (alkanes) or other bending modes like C–O stretching in esters or ethers.

2. 1150–1650 cm^{-1}: Peaks in this region often correspond to C=C stretching (alkenes) or aromatic C=C stretches. It may also include carbonyl (C=O) stretching at ~1650 cm^{-1} if present.

3. 2650–3150 cm^{-1}: A broad absorption in this region often indicates the presence of O–H (alcohol or phenol) or N–H (amines or amides) stretching. A sharp peak could be attributed to C–H stretching (alkanes, alkenes).

4. Above 3150 cm^{-1}: This region often contains N–H stretching (amines) or the broad O–H stretching from alcohols and carboxylic acids.

5. Broad Dip Around 3400 cm^{-1}: Suggests the presence of O–H (hydroxyl group) bonds, possibly from alcohols or water.

6. Sharp Dip Below 2000 cm^{-1}: If present, this can indicate C≡C (alkyne) or C≡N (nitrile) stretching vibrations.

Chapter-6

Discussion and Future recommendation

6.1 Discussion:

The increasing global demand for sustainable and renewable energy sources has drawn significant attention to biomass-based energy production. This study aimed to explore the potential of *Eichhornia crassipes* (commonly known as water hyacinth), an abundant and problematic aquatic weed, as a viable feedstock for biofuel production through the pyrolysis process. The results of this research confirm that water hyacinth, despite being considered a nuisance in many regions due to its invasive nature, holds remarkable promise as a renewable energy source when properly processed.

The research highlights several important aspects:

1. **Environmental Significance**: Utilizing water hyacinth for biofuel production offers a dual benefit: controlling the spread of this invasive species and converting it into useful energy, thereby contributing to ecosystem restoration and energy security.
2. **Economic Viability**: The process of converting an easily available, low-cost biomass into energy has strong implications for local economies, especially in developing countries like Bangladesh, where energy demand is growing and biomass resources are widely available.
3. **Technological Feasibility**: The pyrolysis technique, though requiring initial setup and controlled parameters, is relatively simple and scalable. With advancements in reactor design and temperature control, the process can be optimized for higher yields and improved energy recovery.

Despite its promising potential, this study also acknowledges certain limitations. The quality of bio-oil produced still requires further refinement to meet commercial fuel standards. Additionally, the energy input required for the pyrolysis process must be considered in order to assess the overall energy efficiency and carbon footprint of the method. Future work should focus on upgrading the pyrolysis system, integrating catalytic processes, and exploring co-feeding with other biomass types to improve fuel quality and production efficiency.

6.2 Future recommendation:

1. Exploration of Alternative Catalysts:

   Investigate other catalysts (e.g., metal oxides, zeolites, or biomass-derived catalysts) to improve yield and reduce environmental impact. Compare the efficiency and sustainability of $FeCl_3$ with alternative catalysts.

2. Optimization of Pyrolysis Parameters:

   Conduct studies to optimize pyrolysis temperature, heating rate, and residence time for maximizing biofuel yield and quality. Explore the role of pressure in enhancing reaction efficiency.

3. Life Cycle Assessment (LCA):

   Perform an LCA to evaluate the environmental, economic, and social impacts of biofuel production from water hyacinth. Compare the LCA of $FeCl_3$-catalyzed biofuel production with other biofuel production methods.

4.Product Analysis and Applications:

   Analyze the by-products (e.g., biochar and syngas) for their potential applications in agriculture or energy. Investigate upgrading bio-oil to high-value chemicals or transportation fuels.

5. Scaling Up the Process:

Research the feasibility of scaling up the process from lab-scale to pilot-scale or industrial-scale production. Address engineering challenges and economic viability in real-world applications.

6. Use of Other Invasive Biomass:

Expand the study to include other invasive plant species as feedstocks for biofuel production. Evaluate the efficiency of $FeCl_3$ as a catalyst for a wider range of biomass.

Chapter-7

Conclusion

7.1: Conclusion

Through comprehensive experimentation and analysis, the pyrolysis process was shown to effectively convert water hyacinth into three primary products: bio-oil, bio-char, and pyrolytic gas. Among these, bio-oil is of particular interest for its potential application as a liquid fuel alternative. The characteristics of the obtained bio-oil—such as its calorific value, viscosity, and elemental composition—indicate that it can be refined and utilized as a substitute for certain fossil fuels, especially in domestic and industrial heating applications. Bio-char, a byproduct of the process, also demonstrated significant energy value and can be further used as a solid fuel or soil conditioner, enhancing the circular economy and supporting sustainable agricultural practices.

In conclusion, the conversion of water hyacinth into biofuel through pyrolysis stands out as a sustainable and innovative approach to addressing both environmental and energy challenges. With further research and development, this method can be scaled and adapted to various regions, making it a practical component in the global shift toward renewable energy. This thesis contributes a significant step toward harnessing underutilized biomass for clean energy, reinforcing the idea that even invasive species can become valuable resources when approached through scientific innovation.

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