Assessing the Removal Efficiency of Microplastics in Aqueous Solutions Using Tobacco Waste Biochar

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Approval Sheet

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Abstract

Plastic pollution is a pressing issue in developing countries like Pakistan. It poses serious impacts on environment, while affecting aquatic ecosystems and consequently human health. The issue remains majorly unaddressed in Pakistan, while there are a few research studies on microplastics occurrence and abundance, there still is a gap for research focused towards the removal of microplastics from water bodies. With our final year project, we are contributing towards the accomplishment of Sustainable Development Goals (SDGs) 6 and 12, via proposing a low-cost and sustainable approach for the removal of microplastics from water. Our idea focuses on the utilization of biochar, a promising adsorbent that can be easily fabricated and exhibits excellent adsorption capabilities for pollutants.

In this project, we aimed to enhance the adsorption efficiency of biochar by magnetizing it, enabling easy removal from water. To develop an eco-friendly adsorbent and establish a link with industries for minimization of their waste, we obtained tobacco waste from vendors affiliated to a renowned international company.

Research studies revealed that the most abundant type of microplastics in Rawal Lake, Islamabad to be HDPE which were synthesized in laboratory with various size ranges. The removal efficiency of the magnetized biochar for microplastics reached up to 94 percent after adsorption. To ensure the sustainability and cycle stability of the proposed solution, the magnetized biochar was regenerated and reused in the same process. Through regeneration, an impressive efficiency of up to 92 percent was maintained, indicating that our approach not only effectively removes microplastics but also offers an efficient waste management strategy.

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List of Abbreviations

Word	Abbreviations
Microplastics	MP
Milligram	mg
Micrometer	µm
Pakistani Rupees	PKR
Zinc Oxide	ZnO
Ferric Oxide	Fe_3O_4
Pakistan Tobacco Company	PTC
High Density Polyethylene	HDPE
Low Density Polyethylene	LDPE
Polypropylene	PP

Chapter 1: Introduction

1. Introduction

This chapter serves the purpose of introducing the background of the issue and mission statement of our project by shedding light on the alarming concern of increase in microplastics concentration in aquatic bodies, their health effects, impacts on environment (air, water quality), on marine life and subsequently, the food chain. Moreover, further insights into the use of biochar as an adsorbent material for the potential solution to microplastics pollution in aquatic medium. The chapter also introduces the objectives of the research project.

1.1 Background

Plastic production has expanded over the years due to it being a cheap alternative to many other available materials, its production increased exponentially, from 2.3 million tons to 448 million tons in a time span of almost 70 years and is expected to double in coming years (National Geographic Society, 2021). Its extensive applications in almost every sector, makes it a massively produced material and hence leads to more pollution that contaminates almost every environment (Ilyas et al., 2018). Plastic might have seemed as a cheap and durable option in its early years but the waste generated by it is a major concern that has been ignored in past globally and still is a neglected issue in Pakistan.

Lack of plastic waste management and absence of proper collection and disposal practices is a major threat to environment. It takes hundreds of years for plastic to decompose. With the current production rates, it will only lead to more harm than good.

1.1.1. Plastic waste and population

The increase in population is one of the leading causes of ecological pollution. The growing population means an increase in demand of plastic and subsequently vast amount of waste production (Alabi et al., 2019). Especially with the convenience of easy disposability, single use plastic has become popular among masses and although it might seem as an easy option but the catastrophes attached to it are way bigger than its benefits.

1.1.2. Plastic Pollution in Pakistan

A country like Pakistan where even proper waste collection facilities are unavailable, recycling is a far-fetched concept. The fate of plastic waste is burning or dumping which not only pollutes the land but also create air and water pollution. Plastic waste mismanagement is highest in Pakistan among all the countries of South Asia (Mukheed et al., 2020).

1.1.3. Plastic Pollution in Oceans

Research shows that about 8 million tons of total plastic waste is being dumped into the ocean intentionally on a global scale. A single use plastic bag takes hundreds of years to decompose. A waste contribution of almost 30 percent has been reported because of just wrappers and plastic containers and bottles contribute about 15 percent to it. This leads to excess dumping in oceans (National Geographic Society, 2021). Figure 1 shows plastics in oceans.

Figure 1: Plastics in ocean mixing with marine flora (Photograph by Steve De Neef, NAT Geo Image Collection, 2019)

1.2. Theory

This project focuses on the removal of microplastics from aqueous medium. In order to understand the removal aspects of microplastics, it is really important to explore the background of problem and relate the abundance of microplastics, its health implications and environmental impacts with the project's goal.

1.2.1. Microplastics

Microplastics are referred to the plastic particles with size smaller than 5mm *(Arthur et al., 2009; Cole et al., 2009).*

Plastic waste disperses into the oceans in the form of small fragments via various processes like degradation, and weathering of particles. This leads to the production of plastic particles smaller than 5mm, namely microplastics. Such types of microplastics that are a result of breaking down are called secondary microplastics. Whereas the plastic pollution from cosmetic industries

(Lechner & Ramler, 2015) in the form of microbeads etc. already exists in the size range of microplastics and are called primary microplastics. Figure 2 represents the microplastics in the ocean from 1950 to 2050.

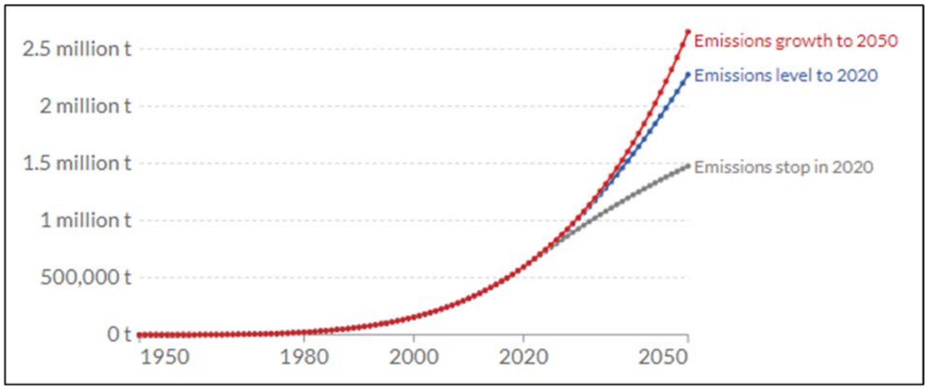

Figure 2: MPs accumulation in the surface ocean, 1950 to 2050 (Hannah Ritchie, 2018)

1.2.2. Microplastics and marine life

Scientists have regarded plastics as a hazardous waste due to its fatal impact on marine animals via ingestion and entanglement (Farrel & Nelson, 2013; Alimba et al., 2019). This continues to harm not only the marine organisms but also humans when the same fish or sea creatures are consumed by humans or other animals. So, microplastics are not only directly leading to catastrophic effects on marine life but also affecting other organisms via the food chain (Okeke et al., 2022).

1.2.3. Health implications of microplastics

More than a hundred marine species are reported to be contaminated with microplastics and we end up consuming the same fish. We are consuming microplastics via packaging, bottled water and even now a research has confirmed that they are present in teabags as well *(Afrin et al., 2022*). WHO confirmed the presence of microplastics in bottled water in 2018 (*WHO, 2019*). Other than that, we are exposed to plastics in almost every way in our day-to-day routine and that exposure leads to the ingestion of these particles into our body and adsorption onto our skin. Thousands of particles of MPs present in 1L of drinking water (*Novotna et al., 2019*). Microplastics have been reported to present in human placenta (*Thomas, 2022*). There is very limited research available on microplastics health hazards but it is believed by some scientists that it can be carcinogenic in nature due to the presence of toxins in them that are used in plastic manufacturing (Teuten et al., 2009). They are reported to cause Dermatitis and some lungs complications as well. They can also lead to cell dysfunction, apoptosis, genetic mutation etc (*Yee et al., 2021*).

1.2.4. Microplastics occurrence in Pakistan

Research available on microplastics occurrence and distribution is very limited in Pakistan. Little to no work has been published or reported on this subject. Among the very few studies, one study of Rawal Lake explores the occurrence and abundance of microplastics in the lake. Polyethylene has been reported as a dominant type of MPs in the tributaries of Rawal Lake. Microplastics present were in a range of 6.4±0.5 particles$/m^3$to 8.8±0.5 particles$/\mathrm{m}^3$ *(Bashir et al., 2022).*

1.2.5. Microplastics removal via adsorption

Various conventional physical, biological and chemical techniques can be used for microplastics removal, including MBR, coagulation, AOP and agglomeration etc. Some of these techniques can be really effective and can provide high efficiencies as well but the problem is that they are often not very feasible and economically viable. On the other hand, adsorption is quite simple and effective for the removal of microplastics from water *(Abuwatfa, 2021)*.

1.2.6. Adsorption via Biochar

Adsorption is a separation technique in which a material called as adsorbate gets attached to the surface of a solid or liquid material with high porosity, called as adsorbent. Biochar is a material that is prepared from any organic material via pyrolysis. It is a natural adsorbent with characteristics like high porosity, high surface area for adsorption and a carbon rich stable structure. Usually, biomass waste is used as a feedstock. For our project we have used Tobacco waste as a feedstock for our biochar.

1.2.7. Tobacco waste- a potential resource

Tobacco, being one of the biggest cash crops of Pakistan *(Ali et al., 2015),* is also a cause of vast amount of waste. Crop waste generated from tobacco ends up in dumps and gets burned leading to further land and air pollution. Our project proposes the idea of utilizing the tobacco waste and converting it into a useful material i.e., biochar. This biochar will be then used for the adsorption of microplastics from aqueous medium.

1.3. Problem Statement

With the growing concern of plastic pollution in our land, oceans and atmosphere, and its impacts on humans, animals and marine life, it is important to address the problem of microplastics as well that has been reported now even in fresh water.

Microplastics are the emerging persistent pollutant with various environmental and health implications. In Pakistan data availability on microplastics abundance and spatial distribution is little to none. The conventional technologies currently employed for water treatment are not very effective in removing microplastics from water. Hence, with our project we are proposing a solution to microplastics pollution by using tobacco waste from a renowned company in Pakistan to utilize it as a biochar rather than letting it go to waste. The biochar produced will be used as an adsorbent for the removal of microplastics from an aqueous solution. Figure 3 shows microplastics shape, color and type in Rawal Lake.

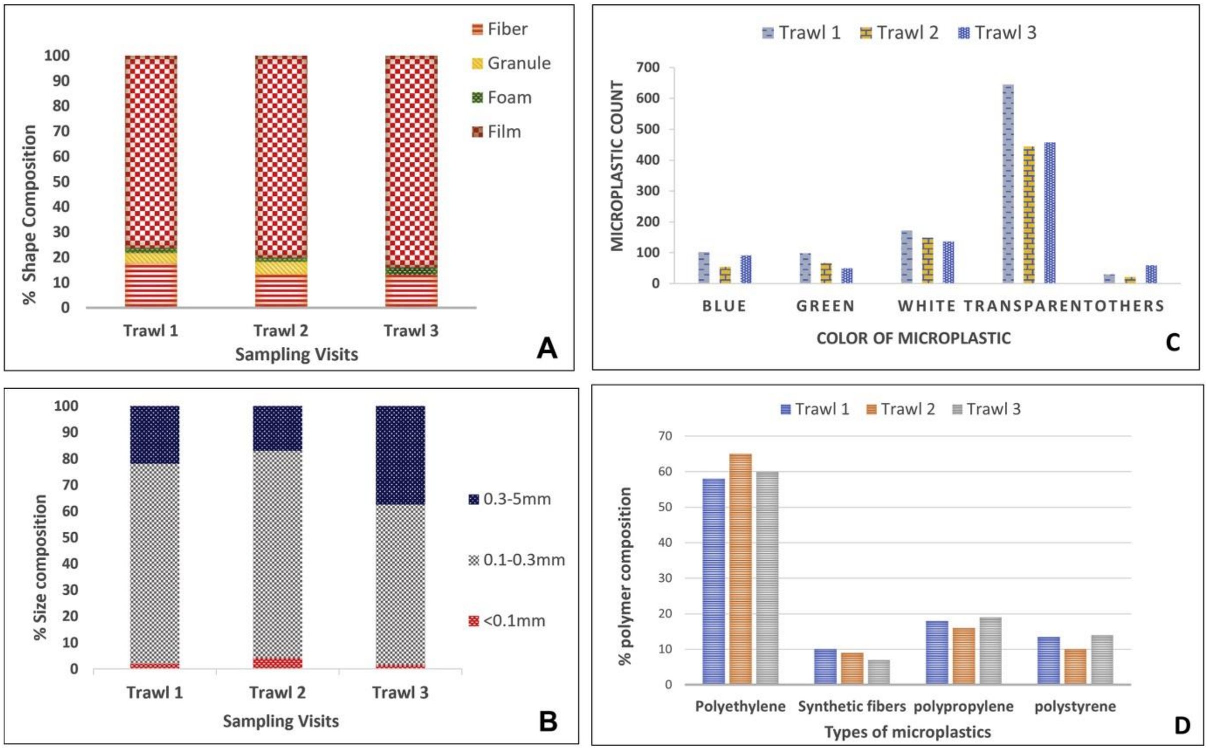

Figure 3: Representation of microplastics in Rawal lake on the basis of (A) Shape, (B) Size (C) Color and (D) Polymer type (Bashir et al., 2022)

The figure above shows the composition and distribution of microplastics in Rawal Lake and this should stress enough on the fact that microplastics are an issue of present and we need to come up with solutions that leads to a higher efficiency while maintaining economic viability and feasibility.

1.4. Research Objectives

The objectives of this research project are as follows:

- Preparation of a low-cost and environment-friendly adsorbent for waste management of Tobacco Industries.

- Comparison of removal efficiency for simple and magnetized biochar and assessment of cycle stability and reusability of magnetized biochar.

1.4.1. Preparation of a low-cost and environment friendly adsorbent

Biochar was prepared via pyrolysis. Tobacco waste from a renowned company in Pakistan was procured as a waste management opportunity for the company and was utilized as a feedstock to convert that waste into a useful adsorbent product. Biochar was prepared at the Energy Centre at the university.

1.4.2. Comparison of removal efficiency for simple and magnetized biochar, and assessment of cycle stability and reusability of magnetized biochar

Biochar produced was then modified to enhance its properties and adsorption capacity. Adsorption experiments for both simple and magnetized biochar were performed and their removal efficiency was compared. Furthermore, to make our proposed solution more sustainable and to ensure cycle stability of the process, the magnetized biochar was reused in the same process.

1.5. Scope

The scope of this project covers the following aspects:

1.5.1. An effective solution for microplastics removal

Microplastics contamination is not only limited to marine life now; they are now being accumulated in our body via the food chain and the consumption of plastic products. So, an effective solution to this problem is the need of the hour and for that adsorption via modified tobacco biochar is proposed as an effective solution for microplastics removal.

1.5.2. Preparation of biochar in accordance to conditions required for high adsorption & yield

The conditions provided for the production of biochar via pyrolysis were decided according to the outcomes like high adsorption and yield. A high temperature and a high retention time was selected in order to prevail slow pyrolysis conditions yielding a high quantity of biochar and a higher surface area and higher adsorption capacity *(Lin et al., 2016).*

1.5.3. Two size ranges of MPs & shape decided as per the previous studies on the occurrence of MPs in Rawal Lake

A Rawal Lake study explores the occurrence and abundance of microplastics in the lake. Polyethylene has been reported as a dominant type of MPs in the tributaries of Rawal Lake. The most common shape observed was irregular fragments. Microplastics present were in a range of 6.4±0.5 particles/m3 to 8.8±0.5 particles/m^3 *(Bashir et al., 2022).*

1.5.4. Experiments performed for both simple & magnetic biochar and their comparison in removal efficiency was studied

In order to develop a relationship between the removal efficiencies of both simple and magnetized biochar and to understand the improvement in biochar characteristics after modification, experiments were performed for both simple and magnetized biochar and their removal efficiency were compared.

1.5.5. Regeneration & reuse of magnetic biochar to verify cycle stability

To inculcate sustainability in our proposed solution, the concept of reuse was introduced in order to decrease the environmental implications of biochar disposal fate and minimum sludge production. The used magnetized biochar was regenerated via thermal process and was reutilized into the same process to achieve cycle stability.

1.6.SDG Mapping

Sustainable Development Goals (SDGs) are a set of 17 goals that were adopted by the UN in 2015. They serve the purpose of a footprint for the development and prosperity of a nation and its people. Each goal stands for a different issue and aims at achieving sustainability in that very aspect. These goals are an indicator for a prosperous, educated and efficient and environmentally and economically sound future. Our project is mapped majorly by SDG 6 since we are providing clean water and then SDG 3, and 12.

1.6.1. SDG 3

SDG 3 aims for a healthy lifestyle and access to well-being. It promotes equitable and accessible health services, better maternal health, improved mental health and access to equal treatment opportunities.

1.6.1.2. Target 3.9

This target aims at improved environmental conditions with decreased health implications from hazardous materials and toxicants present in air, water or land. It promotes clean water resources and a clean environment. This relates to the health implications microplastics have when they travel the food chain through ingestion or are adsorbed on human skin or any other transport mechanism. With our project we target to reduce the health implications or threats of microplastics by providing an effective solution.

1.6.2. SDG 6

SDG 6 aims for clean water and sanitation. It promotes equitable, adequate access to clean water and sanitation. It also aims for the reduction of pollutants in water and elimination of hazardous materials from water.

1.6.2.1. SDG 6.3

This target aims for the improvement of quality of water by working towards strategies and methods to reduce pollution, and policies for the elimination of dumping practices, promoting the idea of recycling and reuse. This relates directly to the issue of dumping plastics into the ocean leading to microplastics contamination and decreased water quality. With our project we aim to reduce microplastics pollution by employing removal techniques for the existing microplastics in water bodies.

1.6.3. SDG 12

SDG 12 aims for responsible consumption and production. It promotes sustaining production patterns and consumption habits. It further relates to pollution, climate crises and biodiversity loss.

1.6.3.1. Target 12.3

This target aims for the reduction and prevention of waste via reusing, recycling, and proper management. It promotes a sustainable waste management concept that paves the road for a sustainable future. In our project, we are utilizing tobacco waste from a company and producing a useful product from it and then using it again to remove a pollutant from water. Other than that, the reuse of magnetized biochar in the same process to reduce sludge production and other environmental implications of biochar can also be linked with this Target of SDG 12.

Chapter 2: Literature Review

2.1. Importance of Using Tobacco Waste

Tobacco is a major cash crop in Pakistan, and its many consumptions boost the economy. The tobacco sector is the only one in the country that pays its producers promptly for their harvests *(Ali, 2015)*. In Pakistan, Tobacco is largely discarded of and is a readily available agricultural waste. *(Shah et al, 2021)*. The probable outcome of Tobacco stalks (which are generated in large quantities) are cut in fields for microbial turnover, left in fields; and utilized as fuel for cooking at the household level. Tobacco stalks contain a high concentration of nicotine and may create health and environmental hazards if they are blown into surrounding cities or populous towns. *(GALLEGOS A et al., 2017)*. Hence, Tobacco waste can be used for biochar production for its abundance and disposal.

2.2. Selection of Microplastics

Films and transparent color were the two defining characteristics of the microplastics collected. In terms of the percentage of microplastics submitted to polymer identification, HDPE & LDPE and PP predominated with size less than 1 mm (0.3-0.1mm) *(Bashir et al., 2022)*. For the selection of shape of microplastics, research study referred results indicated that the most dominant shape of microplastics was fibers and fragments with the dominant colors were blue, red, black, and transparent *(Irfan et al., 2020)*. Particle size is one of the main parameters impacting the toxicological effects of microplastics, along with type, shape, concentration, and color of the microplastics *(Ding J et al., 2020)*. In general, the more hazardous the particles are to organisms, the smaller the particle size *(Gonçalves J et al., 2021)*. In particular, microplastics with greater specific surface areas have the capacity to absorb more contaminants, increasing their toxicity. On the other hand, the longer the microplastics are held in the body due to their tiny size, the greater the danger of possible harm *(Zhang et al., 2022).*

2.3. Biochar as an Adsorbent for Microplastics

Biochar has various advantages, including increased removal efficiency, a potentially low-cost procedure, and robust immobilization of these microplastics. This is especially possible when biochar is coupled with other materials, which can further entangle the microplastics and increase their size, leading them to become immobile. Biochar has attractive properties that enable the effective removal of microplastics. *(Waad et al., 2021)*

2.4: Conditions for Tobacco Biochar preparation

In the absence of oxygen, biomass is thermally decomposed in pyrolysis. The common byproducts of pyrolysis of biomass are biochar (solid), bio-oil (liquid), and biogas (gas). Biochar with a high carbon content was created by this endothermic method. The substance undergoes pyrolysis when it is heated from room temperature to a peak temperature and then stays for a certain amount of time. Thus, the pyrolysis peak temperature and residence duration are the two most important pyrolysis parameters *(Hasan et al.,2019)*. A research study on production of tobacco stem biochar at different temperatures shows that Biochar made from tobacco stems may not be acceptable for use as a fuel, but it may be developed for use as a soil amendment and adsorbent by optimizing pyrolysis conditions and changes *(Chen et al., 2016).* For the production of tobacco waste biochar with high surface area and cumulative volume, research study was referred which depicts that The BET surface area and cumulative pore volume of tobacco stem biochar generated at a high temperature of 600°C, a retention duration of up to four hours, and a heating rate of 10-15°C min1 were greater than those of other biochar *(Lin et al., 2016).*

2.5. Using Zn modified magnetic biochar

Experiments with various adsorbents such as plain biochar, carbon nanotubes, magnesium, iron, and zinc modified biochar revealed that Zn modified biochar had the greatest removal effectiveness of up to 99.46%, followed by Mg modified biochar, which had a removal efficiency of 98.75%. Zn-modified biochar can be used as an effective microplastics adsorbent*(Wang et al ., 2021).*

2.6. Post magnetization

Biochar can be magnetized either by Pre-magnetization or post magnetization. Zn modified magnetic biochar was achieved through pre-magnetization process for removal of microplastics in previous research studies *(Wang et al.,2021)*. In impregnation method, a precursor solution containing ferric or ferrous chloride is mixed with the biomass, and the resulting biomass is then pyrolyzed at a high temperature in an inert atmosphere. This one-step pyrolysis of $FeCl_3$-loaded biomass can result in the production of biochar with magnetic characteristics but also causes secondary pollution, is expensive, and could not target any desired functional group on the surface of the biochar *(Boudraa et al., 2022)*. In another study, for removal of a material pre magnetization and post magnetization were used for magnetization of cotton straw biochar. The results showed post magnetization showed the best separation performance and the largest adsorption capacity *(Gu et al.,2021).*

CHAPTER 3: METHODOLODY

3.1. Material Selection:

Tobacco is a significant economic crop in Pakistan, a large amount of its waste is discarded every year. We used this waste, which comprises of tobacco stems, pieces, and leaves, as a raw material to produce biochar.

3.2. Collection of Tobacco waste:

Getting tobacco waste from the factory was our first step. The amount of waste that was collected was sufficient to provide enough biochar for our laboratory tests. We received the tobacco waste in the following three forms presented in figures 4, 5 and 6.

Figure 4: Tobacco Leaves

Figure 5: Tobacco Stem

Figure 6:Tobacco Bits

3.3. Preparation of Raw Material:

We washed and dried the raw material twice and then mixed together all three types of waste.

The mixture of waste is presented in figure 7.

Figure 7 : Mixture of Tobacco leaves, bits and stem

3.4. Pyrolysis Equipment Setup

We produced tobacco waste biochar with the help of pyrolysis equipment available in USPCASE, NUST. Figure 8 displays the pyrolysis equipment setup.

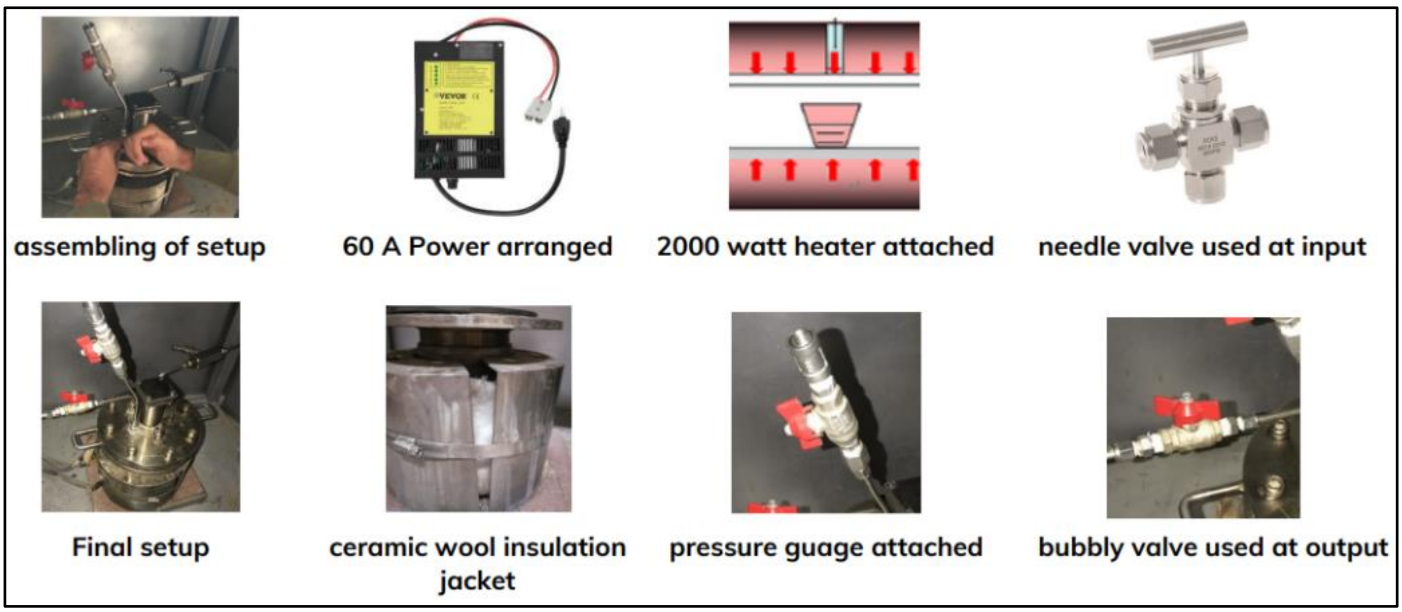

Figure 8 : Pyrolysis Equipment Setup

In order to perform pyrolysis first we set up the equipment by attaching it with a 2000-watt heater along with 60 A power. A needle valve was used at the input and bubbly valve was used at the output. Pressure gauge was attached, and ceramic wool was inserted inside to provide insulation.

3.5 Generation of Biochar

The biochar was produced at 500°C with the heating rate of 12°C/min. The retention time was 4hrs and the weight of the biomass was 345g with a yield of 42.3%.

3.6 Grinding

In order to convert our biochar into fine powder, we used an electric grinder shown in figure 10 from Air and Noise laboratory at IESE, NUST. The biomass was ground for 30 seconds in the grinder and powder form was obtained depicted in Figure 9.

Figure 10: Electric Grinder **Figure 9 : Powdered Tobacco Biochar**

3.7 Magnetization of Biochar

For magnetization following steps were carried out:

1. A thoroughly calibrated mixture of 4.8 g of Iron (III) nitrate nonahydrate, 2.5 g of Zinc nitrate hexahydrate, and 2.5 g of biochar, in a precise defined amount, was prepared. The composition of this amalgam was prepared with the utmost precision and accuracy using 100 milliliters of deionized water. Figure 12 illustrates the mixing of biochar in salts solution. Figure 13 shows magnetization solution for biochar.

Figure 12: Mixing biochar in Fe & Zn solution

Figure 11: Solution of magnetized of biochar.

2. The produced solution was then transferred to a rotary evaporator, an advanced laboratory tool renowned for its effectiveness in separating solvents from solutions by using carefully controlled heating and suction conditions. The solution was transferred completely and smoothly with the least amount of loss or contamination possible.
3. The temperature within the rotary evaporator was then gradually elevated to 50 degrees Celsius, using a state-of-the-art heating mechanism that provided precise control over the temperature settings. This controlled temperature increase was vital for facilitating the subsequent chemical reactions and achieving the desired experimental outcomes.
4. With utmost precision, an appropriate quantity of sodium hydroxide (NaOH), a strong alkaline compound, was added to the solution contained within the rotary evaporator. The addition of NaOH served a crucial role in the progression of the chemical reactions, thus necessitating great attention to detail during its incorporation.
5. Following the NaOH addition, the temperature within the rotary evaporator was further elevated to 80 degrees Celsius. This temperature elevation was achieved through the employment of cutting-edge temperature regulation techniques, ensuring the optimal conditions required for the chemical reactions to proceed efficiently and produce the desired results.
6. The sample within the rotary evaporator was then subjected to a precise and controlled rotation for a duration of 30 minutes. This rotational agitation was crucial for promoting the thorough mixing and reaction of the constituents, enhancing the overall efficiency and effectiveness of the experimental process.
7. After the designated rotation period was completed, It was washed in distilled water for up to five times and the sample was meticulously separated from the solution by means of

filtration, employing a magnet-assisted technique. The magnet facilitated the separation of magnetic components present in the sample, ensuring a clean and efficient filtration process. Stringent measures were taken to minimize any potential loss or contamination during this filtration step.

8. Finally, the filtered sample was subjected to a drying process, which involved carefully removing any residual moisture. This drying procedure aimed to obtain a dry, solid sample suitable for subsequent analysis and characterization. The drying process was conducted under controlled conditions, ensuring optimal results and minimizing the possibility of any undesired alterations to the sample.

Throughout the entirety of the experiment, strict adherence to proper laboratory protocols and the highest standards of precision and accuracy were observed, guaranteeing the reliability and validity of the obtained results.

3.8. MPs Production and Selection

1. In the laboratory, a systematic approach was employed to synthesize a high-density polyethylene (HDPE) sample.
2. After obtaining HDPE pallets, the initial step involved the preparation of microplastics (MPs). To obtain the desired particle size, a fine file, known for its precision, was utilized to meticulously crush the microplastics. This deliberate crushing procedure ensured the production of different size ranges of MPs, facilitating subsequent processing and analysis.
3. Following the precise crushing of the microplastics, an appropriate amount of the resulting crushed MPs was meticulously measured and carefully collected.
4. To create a well-dispersed suspension of the crushed MPs, deionized water, known for its high purity, was chosen as the solvent. The selection of deionized water ensured the absence of any impurities or contaminants that could potentially interfere with the synthesis process. The suspension was prepared by thoroughly mixing the required amount of crushed MPs with the deionized water, using sonication technique for 15 mins to promote homogeneity.
5. After the solution of MPs was prepared, it was passed from two different sieves of <20 um and <30 um.
   - The MPs were carefully collected from both sieves and were dried afterwards.
   - Now we have obtained two different size ranges of MPs for the removal experiments.

3.9. Preparation of MPs Solution for Removal Experiments

For the preparation of MPs solution for removal experiments, 50 mg of MPs were obtained for each size range and were dissolved in 10ml of DI water. These prepared solutions for both size ranges were then treated with simple and MBC.

3.10. Removal Experiment Procedure

1. Varying doses of biochar from 10mg to 100 mg were sequentially added to the prepared MPs solution of each size range, creating different concentrations of biochar.
2. The prepared samples were placed on a shaker for an adsorption experiment lasting 5 hours. The shaker was set at a speed of 180 rpm to ensure consistent mixing.
3. Following the adsorption period, the samples were filtered using a filtration assembly to separate the mixture.
4. The microplastics that were adsorbed onto the filter paper during filtration were carefully collected, and their mass was measured to quantify the amount of adsorbed MPs.
5. The remaining solution, referred to as the filtrate, was then subjected to another filtration step using a 0.2μm filter.
6. After the second filtration, the filtrate was weighed again to determine the mass of the remaining MPs.
7. The efficiency of the adsorption process was calculated for each size range of microplastics, considering the initial mass of MPs, the mass of adsorbed MPs, and the mass of the remaining MPs in the filtrate.
8. To ensure accuracy and reliability, all experiments were performed in triplicates.
9. The pH of the solution was calculated and the removal experiment was also performed at acidic pH 5 by adding HCL to the solution and basic pH of 9 by adding NaOH to the solution and at the neutral pH of 7.

3.11. Regeneration Experiment

The entangled microplastics and biochar after removal experiment was then thermally treated in muffle furnace for 10mins at 500°C, where the microplastics were degraded at high temperature regenerating the biochar.

This regenerated biochar was treated with the microplastics solution with the same concentration and removal efficiency was calculated afterwards.

3.12. Characterization Tests

The following tests were performed during the experiments:

3.12.1. Proximate Analysis

Proximate analysis was performed to check the basic composition of our sample of biochar. We determined the moisture content, volatile matter, fixed carbon, and ash content of our sample. These parameters are essential in assessing the quality and energy potential of biomass.

3.12.2 PSA (Particle Size Analysis)

Particle size analysis was performed to determine the size range and distribution of MPs in a given sample. It involves measuring the dimensions of particles present in a material and generating a size distribution profile. This analysis was important to verify the size ranges of MPs.

3.12.3 BET (Brunauer-Emmett-Teller)

BET analysis is essential in characterizing porous materials, catalysts, and powders, as the surface area influences the reactivity and performance of these materials. The BET test was performed to determine the specific surface area of our sample biochar.

3.12.4 FTIR (Fourier Transform Infrared Spectroscopy)

FTIR was performed twice in USPCASE laboratory. First test was performed on HDPE microplastics generated in laboratory to validate their purity. The second test was performed for microplastics adsorbed on the surface of magnetic biochar to study the peaks and composition after adsorption experiment.

3.12.5 XRD (X-ray Diffraction)

XRD analysis provides information about the arrangement of atoms in a material, crystallographic phases, lattice parameters, and crystallite size. This test was done to prove that the biochar is magnetized with iron and zinc oxides.

3.12.6 SEM (Scanning Electron Microscopy)

Scanning Electron Microscopy is a powerful imaging technique used to obtain high-resolution images of the surface morphology of a sample. Two samples were tested under scanning electron microscope. The first sample was magnetic biochar to study its morphology and compare results with literature. The second sample tested was to validate that microplastics were adsorbed on the surface of magnetic biochar.

Chapter 4: Results and Discussion

This part includes results for biochar from different tests performed, adsorption experiments and removal efficiency calculations.

4.1. Test Results for Biochar

The tobacco biochar yield was 42.3 %.It is a very promising percentage owing to its use as an adsorbent .Following the production of biochar using tobacco waste of the company, different tests were performed on the samples to study the properties. Following are the results of the tests conducted.

4.1.1. Proximate Analysis

The results for proximate analysis are given below in table 1. Different characteristics like volatile combustion matter, ash content, fixed carbon and moisture content in the biochar.

Moisture content	6.5%
Volatile Combustion Matter	24.1%
Ash content	26.7%
Fixed carbon	42.6%

Table 1: Proximate Analysis Results for Tobacco Waste

These are important findings for predicting the biochar properties. The moisture content is observed at 6.5%.The volatile combustion matter is 24.1%.The ash content is found to be 26.7%. The fixed carbon content is determined to be 42.6%, specifying the solid carbon content that is left behind after volatile components and moisture have been removed.

A high fixed carbon content shows a higher percentage of carbon that is left behind after the removal of moisture and volatile components. The fixed carbon content leads to increased energy content indicating that more energy will be produced when it is burned. It also increases the stability, making the sample durable and less susceptible to degradation. High carbon content not only depicts that less VOCs will be generated reducing the risks related to air pollution.

These results depict the various applications of biochar for water treatment, energy and agriculture sector.

4.1.2. BET (Brunauer-Emmett-Teller Analysis)

USPCASE laboratory results received were used to study the surface properties of biochar, that are surface area and pore volume.

The multipoint BET surface area was calculated In multipoint BET surface area the entire surface of the sample is studied including the surface of pores and external surface of material. We used these results because generally this analysis is more consistent. The results are shown in table 2.

Surface area	**6.160 m^2/g**
Pore Volume	0.012 cm^3 /g

Table 2: BET results of Simple Biochar

To validate the results for BET surface area and pore volume, previous research studies were used for reference. The analysis depicts the results of our study match with the figures reported for biochar produced from tobacco in research papers. Specially, the biochar produced at temperatures from 400°C to 600°C, a heating rate of 5 to 25°C and a retention time of one to five hours, resulted in a cumulative pore volume of 0.010 to 0.056 cm^3/g, and a surface area of 2.89 to 10.62 m^2/g *(Lin et al., 2016)*.

The biochar's structure and potential applications in areas like soil amendment, pollutant adsorption, and catalysis can be better understood using the surface area and pore volume.

4.2. Magnetic Biochar Tests Analysis

Different characteristic tests were performed on the prepared magnetic biochar to validate that it was magnetized by the zinc and iron salts. The results of the tests are presented in this section.

4.2.1. X-ray Diffraction Analysis

X-ray diffraction test is used for identification of phases, degree of crystallinity, phase quantification etc. These findings help to understand the structural and composition of the magnetic biochar and its possible use in environmental remediation and magnetic separation. The purpose of this analysis was to identify specific angles and peaks corresponding to Fe_3O_4 and ZnO in the magnetic biochar sample. This was important to observe to validate that the biochar had been successfully magnetized by the method applied. Figure 13 below represents the peaks and angles observed through the analysis of the test.

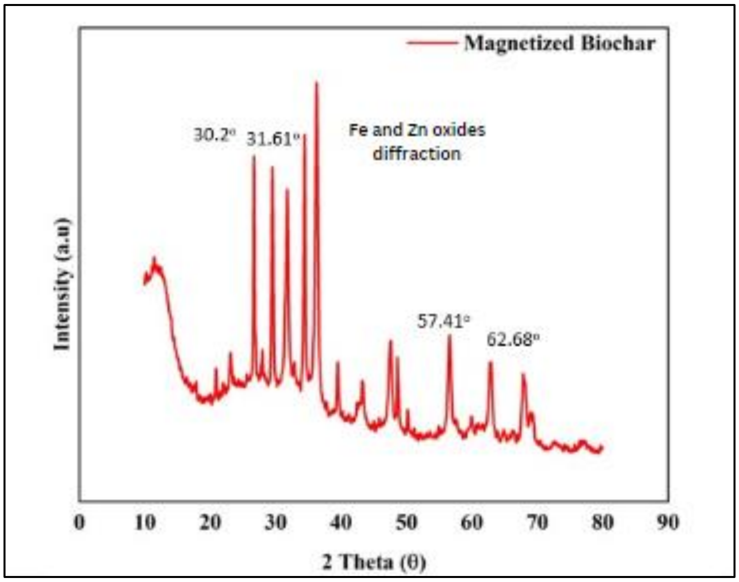

Figure 13: X-ray Diffraction Results for Magnetic Biochar

The main diffraction angles observed, 30.2° and 57.41° are for Fe_3O_4 and 31.61° and 62.68° are attributed to ZnO. All other observed angles and peaks for Fe and Zn oxides are mentioned in table 3 and 4.

Angle	Corresponding Peaks
31.68	773
31.809	336
34.408	271
36.249	210

Table 3: Peaks generated for Fe_3O_4

Angle	Corresponding Peaks
56.422	477
67.838	432

Table 4: Peaks generated for ZnO

The observed diffraction peaks of the sample were compared with the literature. It was established that the diffraction angles match with the characteristic peaks for Fe_3O_4 and ZnO reported. The diffraction angles for Fe_3O_4 were reported at 30.27°, 35.71°, 35.9°, 43.4°, 53.81°, and 57.41° by (Philippou et al., 2019). The diffraction angles for ZnO matched at 31.61°, 34.26°, 36.10°, 47.37°, 56.40°, 62.68°, and 67.72°, as reported by (Pelicano et al., 2017). This evaluation between the observed peaks and the literature reported is proof that the biochar was successfully magnetized with iron and zinc oxides.

4.3. Microplastics Analysis

4.3.1. FTIR Analysis of pure HDPE microplastics generated in laboratory

The figure 14 below represents the absorbance peaks of HDPE microplastics generated in laboratory. The characteristic peaks are observed at 2915 cm^{-1}, 2850 cm^{-1}, 1492 cm^{-1} and 730 cm^{-1}.

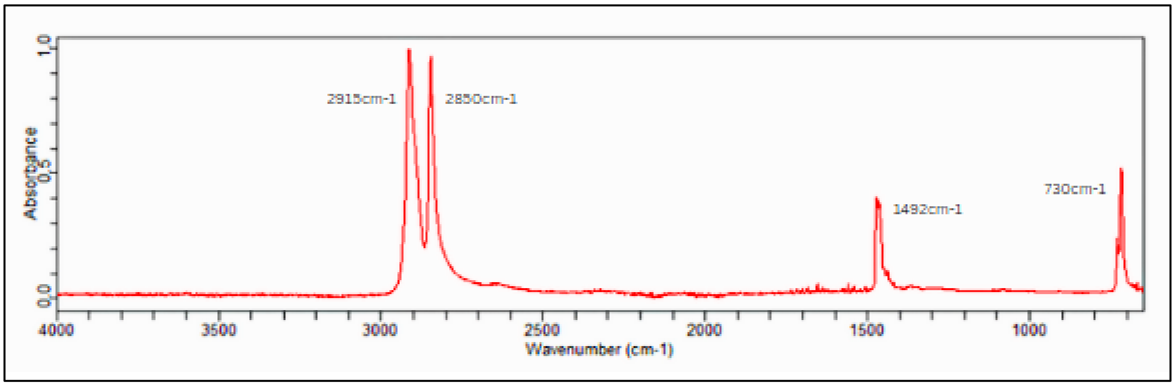

Figure 14: FTIR Results for HDPE Microplastics Generated in Laboratory

It was compared with literature (Prajapati et al.,2021) presented in figure and absorbance peaks accurately matched with the pure HDPE analysis depicting that the HDPE sample produced in laboratory was free of any contaminant.

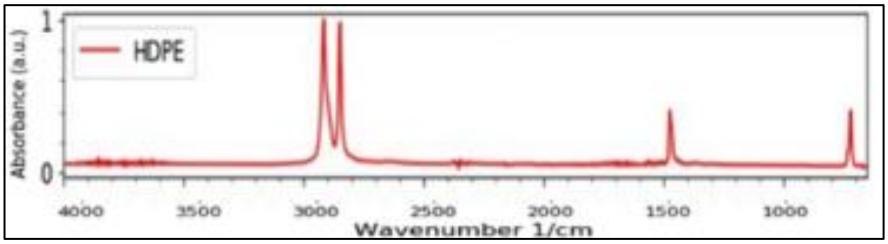

Figure 15:Reference FTIR Spectrum for HDPE Microplastics *(Prajapati et al., 2021)*

The exact comparison of the peaks with the pure HDPE microplastics analysis validates the purity of the sample but also proves that the method used in laboratory was accurate. It denotes that the HDPE sample synthesized was of high quality and satisfied the required specifications.

4.3.2. Particle size analysis

For <30 µm, the results are depicted in table 5. The mean diameter of particles was 17.871 µm.

Diameter	q (%)
1.729	0.176
1.981	0.392
2.269	0.724
2.599	1.031
2.976	1.367
3.409	1.625
3.905	1.911
4.472	2.200
5.122	2.523
5.867	2.881
6.720	3.289
7.697	3.762
8.816	4.346
10.097	5.037
11.565	5.958
13.246	6.707
15.172	7.479
17.377	8.233
19.904	8.309
22.797	8.600
26.111	7.532
29.907	6.017

Table 5: Particle Size Analysis Results for <30 µm

The particle size analysis of <20µm depicted a mean diameter of 2.308µm. The results are shown in table 6.

Diameter	q (%)
0.584	0.123
0.669	0.197
0.766	0.355
0.877	0.689
1.005	1.318
1.151	2.485
1.318	4.541
1.510	7.670
1.729	11.082
1.981	13.373
2.269	14.123
2.599	12.288
2.976	10.272
3.409	7.574
3.905	5.438
4.472	3.645
5.122	2.273
5.867	1.315
6.720	0.708
7.697	0.358
8.816	0.173

Table 6: Particle Size Analysis Results for <20 µm

Overall, the results validated that the microplastics were sieved accurately through the filters and were of the desired size ranges required for removal experiments.

4.4. Removal Efficiency Results with Simple Biochar

The figure 16 shows the removal efficiency calculated by using simple biochar at varying dosages (10 to 100mg) for microplastics with size ranges of <20µm and <30µm. It also shows the removal efficiencies comparison between the two size ranges of microplastics.

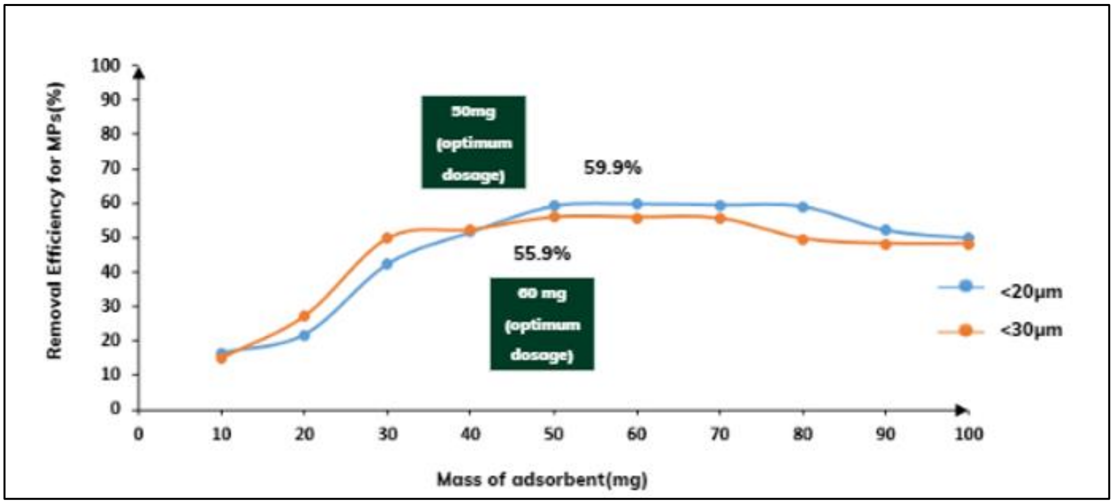

Figure 16: Removal Efficiency Results for Simple Biochar

From the results, it is evident that the optimum dosage of simple biochar for microplastics <20 µm is 50mg, achieving a removal efficiency of 59.9 percent. Similarly, for microplastics <30 µm, the optimal dosage of simple biochar is 60mg, resulting in a maximum removal efficiency of 55.9 percent.

The simple biochar shows removal efficiency, which is relatively high, as reported in the literature *(Wang et al.,2021)*. The results are still not effective for the removal of microplastics without the additional step of magnetization.

These findings highlight the requirement for additional methods like magnetization, to improve the efficiency of biochar in removal of microplastics.

4.4.1. pH Results After Adsorption.

Table 7 demonstrates the effect of simple biochar on the pH of water after adsorption experiment was performed at different dosage of the adsorbent.

	Dosage (Simple Biochar) mg	pH
MPs (<30 µm) **50 mg**	10	7.87
	30	7.90
	50	7.90
	70	7.93
	90	7.98
MPs(<20 µm) **50 mg**	**Dosage**	**pH**
	10	7.65
	30	7.67
	50	7.79
	70	7.83
	90	7.92

Table 7: pH Results after Adsorption with Simple Biochar

The pH observed in the samples were within the range of 7 to 8. This shows that the biochar slightly increased the alkalinity of the water. However, it does not have a significant overall effect on the properties of water.

4.4.2. Removal Experiments for Microplastics at different pH Levels

The results for removal efficiencies calculated for <20µm sized microplastics at different pH are presented in the table 8. This specific size range was used in experiments as it depicted highest removal efficiency.

	pH	Average(mg)	Removal efficiency (%)	pH after removal
50 mg MPs added and 50 mg simple biochar (<20 µm)	5	27.35	54.7	6.9
	7	29.95	59.9	7.90
	9	23.01	46.0	9.02

Table 8: Removal efficiency of Microplastics at Different pH Levels

The results indicate that the highest removal efficiency of 59.9 percent was attained at a neutral pH of 7. At acidic conditions with pH 5, the removal efficiency of 54.7 percent was observed. At alkaline condition with pH 9, the removal efficiency was significantly lower up to 46 percent .These results are comparable with literature, suggesting that microplastics adsorption is more stable in acidic environments as compared to the alkaline conditions *(Jun et al., 2021).*

To conclude, the results demonstrate that the removal of microplastics is pH dependent.

4.5. Removal Experiments Results with Magnetic Biochar

4.5.1. < 20 µm

For different dosage of magnetic biochar varying from 10 to 100 mg, the removal efficiency for size <20µm was calculated by keeping the microplastics concentration constant. The results are shown in table 9.

Biochar Dosage (mg)	MPs Removed (mg)	Removal Efficiency (%)
10	14.55	29.1
20	24.15	48.3
30	39.10	78.2
40	47.12	94.2
50	47.09	94.1
60	46.10	92.2
70	45.55	91.1
80	45.50	91.0
90	44.75	89.5
100	44.72	89.44

Table 9: Removal efficiency for <20µm sized Microplastics using Magnetic Biochar

The maximum removal efficiency of 94.21% was achieved at a minimum dosage of 40 mg representing the efficiency of magnetic biochar for microplastics removal.

4.5.2. < 30 µm

Results were also calculated for size <30µm with different dosage of magnetic biochar varying from 10 to 100 mg, the removal efficiency results are shown in table.

Biochar Dosage (mg)	MPs Removed (mg)	Removal Efficiency (%)
10	11.51	23.0
20	23.10	46.2
30	33.62	67.2
40	46.15	92.3
50	46.07	92.1
60	46.12	92.1
70	45.13	90.2
80	44.98	89.0
90	44.12	87.5
100	44.11	87.1

Table 10:Table 9: Removal efficiency for <30μm sized Microplastics using Magnetic Biochar

The maximum removal efficiency of 92.1% was achieved at a minimum dosage of 40 mg representing the efficiency of magnetic biochar for microplastics removal. After the optimum dosage, the trend becomes constant and then starts to decrease till 100 mg. This is because the active sites are fully filled and there is no more space for adsorption of more particles.

4.5.3. Comparison Between Removal efficiency of Magnetic Biochar for Different size ranges of Microplastics:

The comparison in removal efficiencies of different size ranges of microplastics is shown in figure 17. The results depicts that <30 μm microplastics size range has a lower removal efficiency than <20 μm microplastics. It can be attributed to our particle size analysis results that showed that mean diameter of particles in <30 μm microplastics size range was 17.871 μm quite higher than mean diameter of <20 μm particles that is 2.308 μm. The low specific surface area for bigger sized particles of <30 μm of particles leads to lower efficiency and sites are filled immediately.

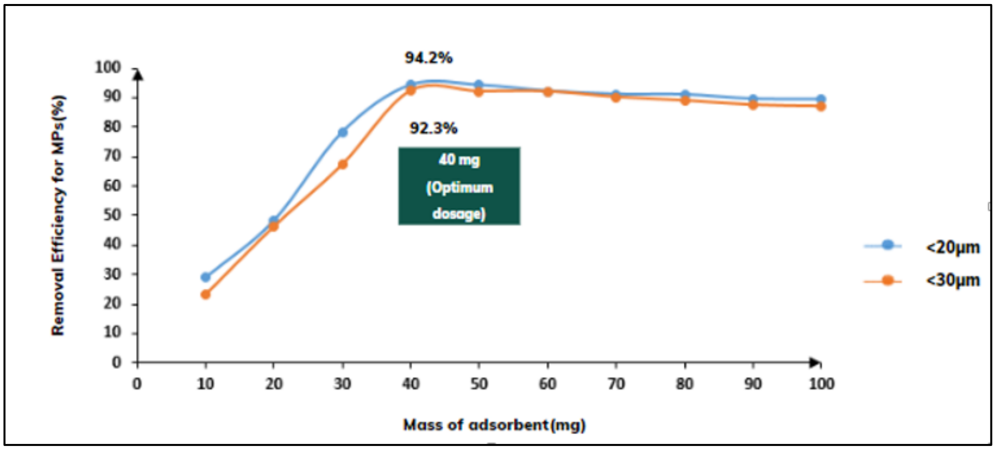

Figure 17: Comparison between Removal Efficiency of <20 μm and <30 μm Microplastics size ranges

4.5.4. pH Results of Water Sample After Removal Experiments

Table 11 explains the effect of magnetic biochar on the pH of sample after adsorption experiment was performed. The pH values recorded are within the range of 7 to 8, indicating that the pH increased to some extent with magnetic biochar experiments.

	Dosage	pH
MPs (<30 µm) 50 mg	10	7.87
	30	7.90
	50	7.90
	70	7.93
	90	7.98
MPs (<20 µm) 50 mg	**Dosage**	**pH**
	10	7.65
	30	7.67
	50	7.79
	70	7.83
	90	7.92

Table 11: pH Results after Adsorption with Magnetic Biochar

4.5.5. Removal Efficiency at Different pH Levels

Removal experiments for microplastics were performed for size range <20µm at different pH levels. The results are presented in table 12. This particular size range was selected because it has the highest removal efficiency calculated using magnetic biochar.

	pH	Average(mg)	Removal efficiency (%)	pH after removal
50 mg MPs added and 50 mg magnetic biochar (<20 **µm)**	5	45.6	91.2	7.2
	7	47.12	94.2	7.9
	9	44.95	89.9	9.0

Table 12: Removal efficiency of Microplastics at Different pH Levels using Magnetic Biochar

The conclusions indicate that at neutral pH of 7, the highest removal efficiency of 94.2 percent was observed. A removal efficiency of 91.2 percent was achieved under acidic conditions that was pH 5.A considerably lower efficiency of up to 89.9 percent was detected in alkaline conditions at pH 9. These results are in accordance with the literature, which proves that microplastics adsorption is more stable in acidic environments as compared to alkaline ones *(Jun et al., 2021).*

4.5.6. Comparison between removal efficiency of simple and magnetic biochar

The figure 18 below shows a comparison between removal efficiencies of simple and magnetic biochar calculated for <20 µm microplastics size range at respective optimum dosages. The comparison clearly proves that magnetic biochar with removal efficiency of 94.21% at a low dosage of 40 mg of adsorbent is more beneficial than simple biochar with low removal efficiency of 59.9% at a high dosage of 60 mg.

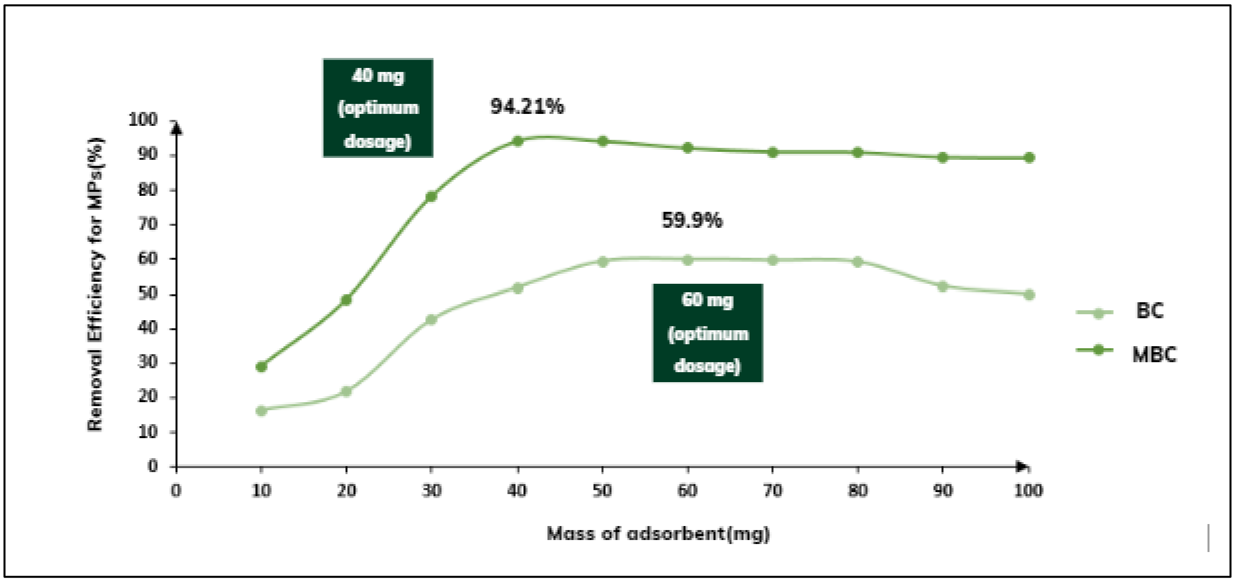

Figure 18: Comparison between Removal Efficiencies of Simple and Magnetic biochar for <20 µm sized Microplastics

The figure 19 shows a comparison between removal efficiencies of simple and magnetic biochar calculated for <30 µm microplastics size range at respective optimum dosages.

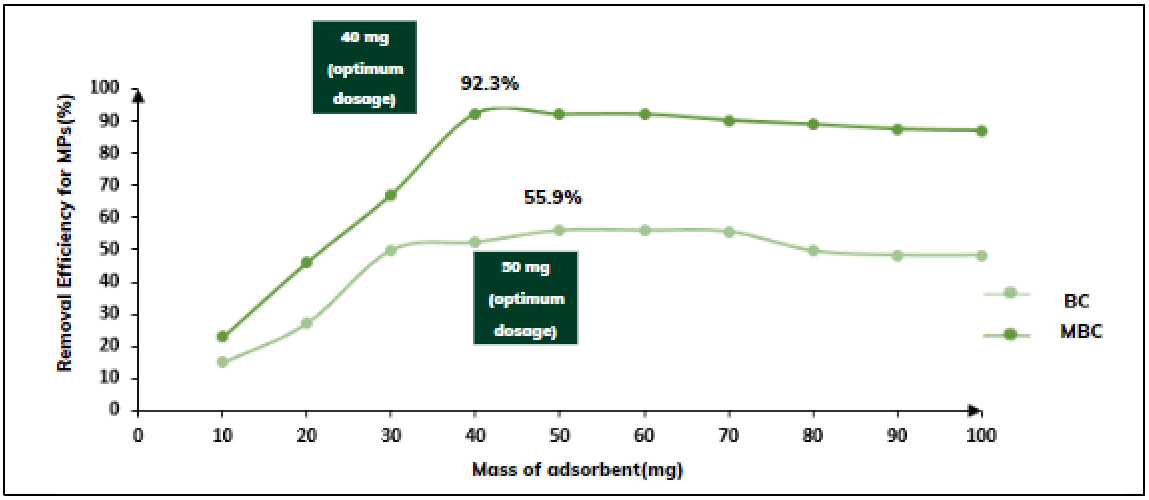

Figure 19: Comparison between Removal Efficiencies of Simple and Magnetic biochar for <30 µm sized Microplastics

The comparison validates our findings again that magnetic biochar with a low dosage of 40 mg gives higher removal efficiency of 93.3%. The simple biochar exhibits even lower removal efficiency for this size range at 55.9% at optimum dosage of 50 mg. These two findings show that magnetic biochar can be used in future applications for removal of microplastics and its low dosage represents applications for industries where cost efficiency is an important factor in water treatment.

4.6. Tests for Magnetized Biochar and Adsorbed Microplastics on its Surface

4.6.1. FTIR Analysis

The presence of HDPE microplastics on the surface of magnetized biochar were validated by FTIR analysis. The obtained results and corresponding peaks are presented in figure 20.

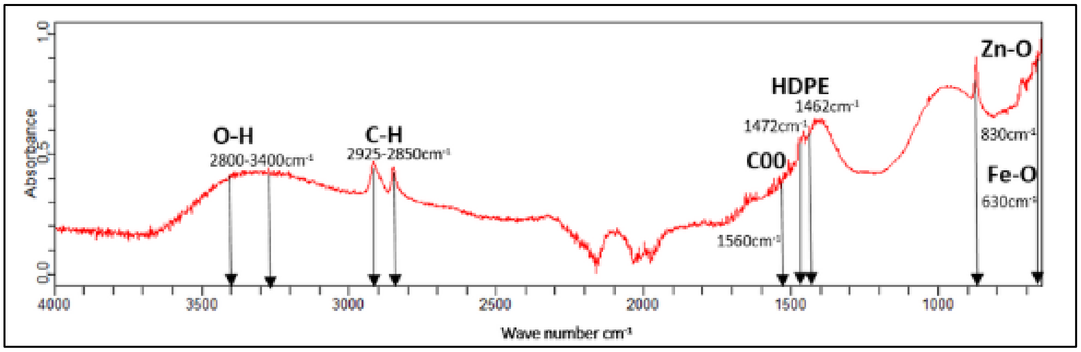

Figure 20: FTIR Spectrum for Magnetized Biochar and Adsorbed Microplastics on its Surface

The specific peaks displayed in the graph confirms the presence of HDPE microplastics. These peaks correspond to bonding patterns specific to microplastics and functional groups in magnetic biochar. Moreover, the presence of certain peaks indicated a bond between metal-oxygen and microplastics, suggesting the successful loading of metal ions onto the surface of the magnetic biochar and subsequent formation of a bond with the microplastics.

The broad band in the range of 2800-3400/cm attributed to the O-H stretching of hydroxyl groups in the biochar *(Bekiaris et al., 2016).*

Peaks at 2925 and 2850/cm were observed, indicating the aliphatic compounds in the biochar and C-H bonds *(Leifeld, 2006).*

Furthermore, the peaks observed at 1560/cm in the biochar spectrum shows the stretching vibration of COO- groups corresponding to presence of aromatic compounds *(Leng et al., 2015).*

For the HDPE spectrum, characteristic peaks were observed at 1472 and 1462/cm, which is comparable with the literature for microplastics. These peaks provide evidence for the presence of HDPE microplastics and confirm their identity *(Chen et al., 2021).*

The peak at 830/cm represents the presence of ZnO in the HDPE spectrum. This validates the integration of ZnO into the HDPE microplastics *(Chen et al., 2021).*

To conclude, presence of peaks at 755/cm in the HDPE spectrum represents the formation of metal-oxygen-microplastics bonds, indicating a possible interaction between metal ions and the HDPE particles *(Wang et al., 2021).*

4.6.2. SEM (Scanning Electron Microscope Analysis)

Scanning electron microscopy (SEM) examination was carried out at a magnification of 50 µm in order to strengthen the validity of our study findings and gather more knowledge about the surface of the magnetized biochar. The obtained images are presented in Figure 21.

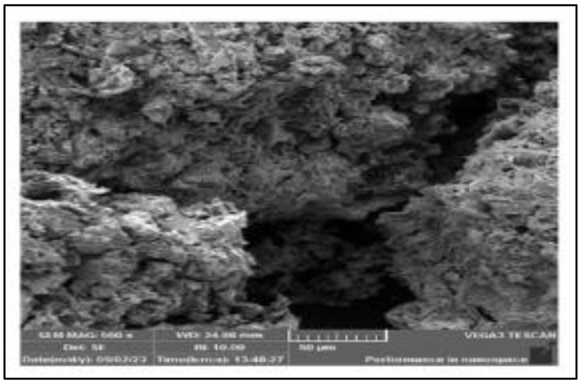

Figure 21: SEM results for Zn modified Magnetic Biochar

In order to validate our findings, we compared the SEM image results with an illustration of a magnetized biochar surface that had been published in the literature *(Wang et al., 2021).* The reference image shown in figure 22 is used as a benchmark for evaluating and validating our own SEM results.

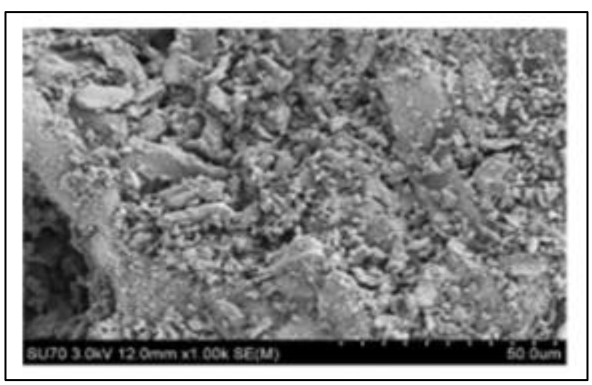

Figure 22: Reference SEM Images for Magnetic Biochar *(Wang et al., 2021)*

By consulting the literature, we can determine how closely our SEM picture resembles the published image, supporting the validity and dependability of our findings. This comparative study links our findings to accepted results by adding more proof to structural features of the magnetized biochar.

4.6.3. SEM Analysis of Microplastics Adsorbed on Magnetic Biochar Sample

The sample was thoroughly examined with scanning electron microscope to look into the possibility of microplastics being adsorbed on the Zn-modified biochar surface. The visual representation of the microplastics being adsorbed on the surface of the biochar is provided by figure. The presence of adsorbed microplastics on the surface of magnetized biochar is confirmed by comparing this picture to a prior sample of Zn-modified biochar in figure 23. This validates the results of our research and shows the effectiveness of the removal experiments carried out.

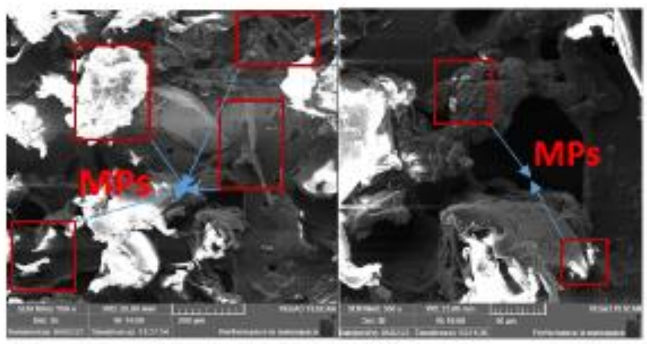

Figure 23: SEM Analysis of Microplastics Adsorbed on Magnetic Biochar

4.8. Cost

The cost of raw material was zero as it was waste obtained from company. The total cost calculated was 100 to 200 per kilogram for production of biochar in USPCASE laboratory. It is sold at a price of 500 per kilogram at commercial scale as induced from the survey from different vendors in Pakistan.

For magnetized biochar, our experiments utilized 2.5g of $Zn(NO_3)_2 \cdot 6H_2O$ & 4.8g $Fe(NO_3)_3 \cdot 9H_2O$ to magnetize 2.5 g of simple biochar. The additional costs added to the sample were 25 PKR for zinc salt and 45 PKR for iron salt utilized in magnetization.

4.8.1. Cost Analysis

The magnetic biochar showed an excellent adsorption capacity up to 94 percent which shows that it is possible to completely remove a significant number of microplastics particles in 200 to 500 kilograms. When extrapolating this to a bigger scale, the magnetic biochar used will be more but it can still prove to be a financially viable option for removing a significant number of microplastics.

From a financial standpoint, this can be perceived as a favorable scenario. The significant amount of microplastics that can be removed makes the expense of using magnetized biochar for removal reasonable. Hence, this method is a practical way to deal with microplastics pollution.

4.9. Testing the Effect of Time on Magnetic Properties of Magnetic Biochar

The removal efficiency was assessed over time to assure the magnetized biochar's long-term efficacy and stability. The removal efficiency results calculated over a period of two days after magnetization are shown in the table 13.

Time	Removal Efficiency (%)
Same day as the magnetization of biochar completed	94.20%
2 days after the magnetization of biochar	94.13%

Table 13: Effect of Time on Magnetic Properties of Magnetic Biochar

It is noteworthy result that during the two days, the removal efficiency of the magnetic biochar did not decrease majorly. This can be due to suitable maintenance and storage procedures, which are required in preserving magnetic properties of biochar.

The biochar was kept away from moisture and sunlight in a cold and dry place. To prevent any modification and decrease in the magnetic properties of biochar, these conditions are essential. The magnetic biochar has to be handled very carefully to avoid any damage that would have affected its removal efficiency capability.

The removal efficiency was stable across the two-day observation period by following the necessary procedures mentioned.

4.10. Regeneration Experiment Results

Table 14 presents the removal efficiency results after the regeneration of biochar. The regenerated biochar was used for a removal experiment targeting <20μm sized microplastics. The recorded removal efficiency was 94.2% and after regeneration, the efficiency slightly dropped to 92.7%.

Removal efficiency before regeneration (%)	Removal efficiency after regeneration (%)
94.2	92.7

Table 14: Removal Efficiency after Regeneration

The efficiency slightly decreased but it is an important finding that the removal efficiency remained above 90%. This indicates the cycle stability of the biochar produced in this study. These results also highlight the recycling and reusing benefits of the biochar in water treatment and its ability to maintain a high level of removal efficiency after regeneration.

4.11. Proposed waste management plan for the company

Figure 24 below shows a plan that has to be proposed to the company for waste management.

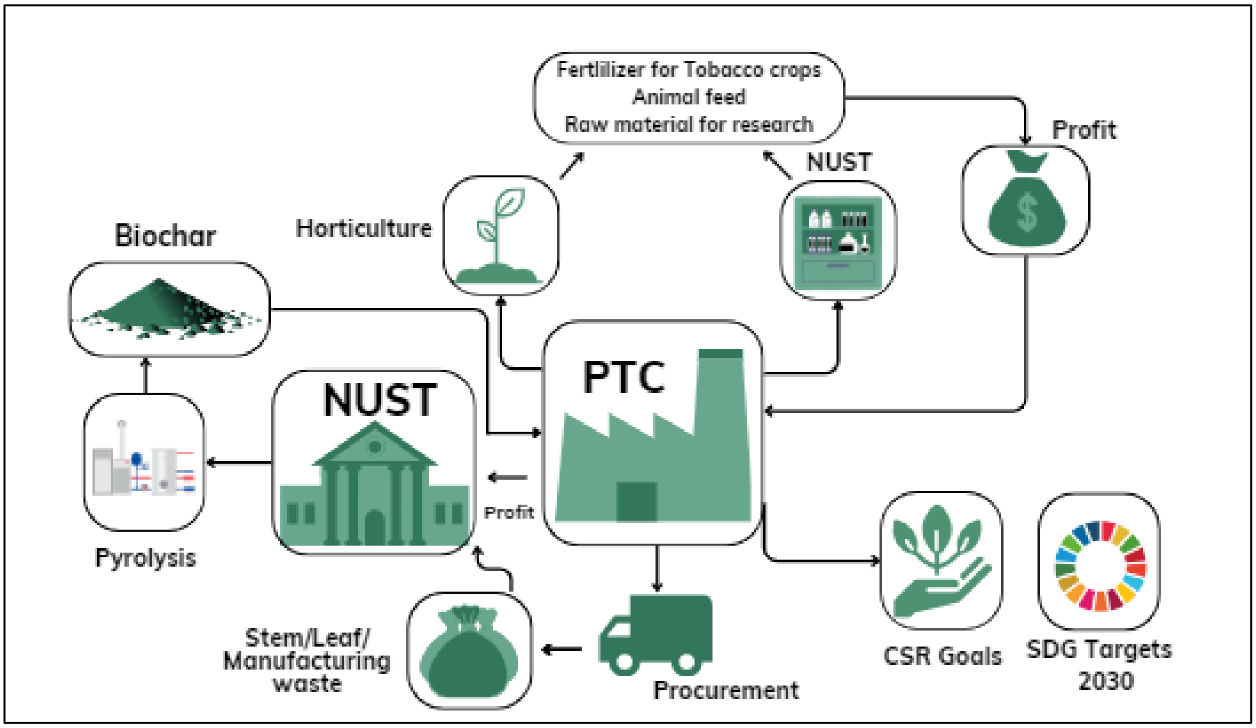

Figure 24: Proposed waste Management Model for Company

The waste management model is as followed: raw material will be obtained from the company. This raw material will subsequently be transformed into biochar in NUST using pyrolysis. The company will get the biochar produced and will be able to profit from it. This biochar may be utilized in horticulture, where it can be used as animal feed. This biochar may also be used as a fertilizer for tobacco crops by the company. Furthermore, they may work with research organizations like WASA, or academic institutes like NUST for research purposes on the waste and biochar. This will pave the way for industry and academia to collaborate. Furthermore, via waste management, the company will be able to meet its CSR and SDG commitments by 2030.

Chapter 5: Recommendations and Conclusion

5.1. Recommendations

5.1.1. Using different Biochar

The future advice involves looking into different biomass waste for production of biochar as potential microplastics adsorbents in place of tobacco biochar. This suggestion attempts to increase the adaptability and sustainability of microplastics removal methods while considering any potential drawbacks and issues related to using tobacco as a source for biochar.

5.1.2. Moving to Pilot Scale

The research at the thesis level is concentrated on evaluating the effectiveness of employing magnetic tobacco biochar for eliminating microplastics. This entails carrying out tests and data analysis in a controlled laboratory environment. The results of the thesis offer insightful information about the merits of using magnetic tobacco biochar as a potential method for removing microplastics. However, more work needs to be done before the technology can be used in practical ways in settings like wastewater treatment plants. After magnetic tobacco biochar's efficiency in removing microplastics is proven at the laboratory stage, investigations at the pilot scale should be carried out. This entails more accurately imitating real-world settings by reproducing the process on a greater scale. The results of the pilot-scale tests would be vital in determining the system's performance, difficulties, and viability in a wider operating configuration.

5.1.3. Life Cycle Assessment

The life cycle assessment for tobacco biochar in relation to the removal of microplastics would entail evaluating and quantifying the environmental costs connected with each step, such as the production of tobacco, the transformation of tobacco into biochar, the use of biochar in the removal of microplastics, and the disposal or repurposing of used biochar. An LCA allows researchers to pinpoint and measure the key points in the life cycle—hotspots—where major environmental consequences happen. This information can be used to optimize the technology and reduce its total environmental impact. Additionally, by considering both its effectiveness and its environmental repercussions, it can help decision-makers decide whether to accept and use tobacco biochar for the removal of microplastics.

5.1.4. Using tobacco adsorbent to clean up tobacco crops' soil

Investigating magnetic tobacco biochar's potential to lower the number of pollutants present in tobacco crop soils would be the main goal. This can be done by carrying out a series of studies utilizing soil samples that have been polluted with typical tobacco cultivation contaminants like nicotine, polycyclic aromatic hydrocarbons (PAHs), and heavy metals *(Ndoung et al., 2021)*. Investigating the possible advantages and difficulties of this strategy would be learned by investigating the application of magnetic tobacco biochar for soil restoration in tobacco crop growing areas. It can aid in the creation of environmentally responsible and environmentally sound farming techniques for tobacco, thereby lowering the dangers of tobacco crops being contaminated and fostering healthier agricultural systems.

5.1.5. Investigating Microplastics in Aquatic Environment

Examining the prevalence of microplastics in aquatic environments, calculating their concentration and size distribution, and looking into potential sources of microplastics pollution. To ascertain the prevalence of microplastics, surveys or sample campaigns should be carried out in a variety of waterways, including rivers, lakes, and oceans. Microplastics can be recognized and quantified using methods like spectroscopy, polymerase chain reaction (PCR), and microscopy *(Kye et al., 2023)*. The Project offers insights on the efficacy and practicality of magnetic tobacco biochar as a viable remediation method for eliminating microplastics from water.

5.1.6. Microplastics in Cosmetics Industry:

One of the proposals for the project is to broaden the investigation by concentrating on businesses, like the cosmetic industry, to determine the level of microplastics present in these items. Because microplastics are widely used in many personal care items, including toothpaste, scrubs, and cosmetics, the cosmetic sector has been a large contributor to microplastics pollution. These products frequently include microplastics such as thickeners, binders, or exfoliates *(Yuwen Zhou et al., 2023)*. However, these compounds can end up in aquatic settings after being wiped off and into wastewater systems, endangering ecosystems, and marine life. Expanding the study to evaluate the prevalence of microplastics businesses, including the cosmetic industry, will aid in identifying their role in microplastics contamination. This knowledge is essential for creating focused initiatives to lessen microplastics contamination, encourage sustainable behaviors, and safeguard the ecosystem.

5.2: Conclusion

We worked with a tobacco company on our research to investigate the viability of employing tobacco waste as an economical and environmentally friendly adsorbent for waste management. Tobacco waste was used to make an adsorbent for microplastics, allowing us to transform a troublesome waste product into a useful resource. This not only solves the problem of managing tobacco waste, but also helps reduce microplastics contamination, which is an increasing environmental concern. Finally, because of our partnership with the tobacco industry, we were able to develop a waste management solution that is both economical and environmentally benign. We proved the capability of magnetic tobacco biochar produced from tobacco waste to remove microplastics. This novel strategy may have real-world applications in combating microplastics contamination and offering a long-term answer for the disposal of cigarette waste.

The project's goal was to assess the effectiveness of microplastics removal using magnetic tobacco biochar (Zn-MBC), a particular kind of biochar. The efficiency of Zn-MBC in eliminating microplastics was investigated through tests and data analysis. The findings show that Zn-MBC exhibits a remarkable removal effectiveness of up to **94.21%.** This indicates that the Zn-MBC treatment was successful in removing **94.21%** of the microplastics particles from the experimental setting. This considerable removal efficiency illustrates the potency of Zn-MBC as an adsorbent for the removal of microplastics.

Chapter 6: Bibliography

1. Jun Wang, Chen Sun, Qun-Xing Huang, Yong Chi, Jian-Hua Yan. (2021). Adsorption and thermal degradation of microplastics from aqueous solutions by Mg/Zn modified magnetic biochars, Journal of Hazardous Materials. Volume 419, 126486, ISSN 0304-3894.
2. Tahira Irfan, Sofia Khalid, Mahwish Taneez, Muhammad Zaffar Hashmi. (2022). Plastic driven pollution in Pakistan: the first evidence of environmental exposure to microplastic in sediments and water of Rawal Lake. Environmental Science and Pollution Research. Volume 27, 13, ISSN 15083-15092.
3. Waad H. Abuwatfa, Dana Al-Muqbel, Amani Al-Othman, Neda Halalsheh, Muhammad Tawalbeh. (2021). Insights into the removal of microplastics from water using biochar in the era of COVID-19: A mini review, Case Studies in Chemical and Environmental Engineering. Volume 4, 100151, ISSN 2666-0164
4. Atif Bashir, Imran Hashmi. (2022). Detection in influx sources and estimation of microplastics abundance in surface waters of Rawal Lake, Pakistan, Heliyon. Volume 8, e09166, ISSN 2405-8440.
5. Yanhui Lin,Wei Yan,Kuichuan Sheng. (2016). Effect of pyrolysis conditions on the characteristics of biochar produced from a tobacco stem. Waste Management & Research. Volume 34.
6. Hanping Chen, Guiying Lin, Xianhua Wang, Yingquan Chen, Yingpeng Liu, Haiping Yang Jingai Shao. (2016). "Physicochemical properties and hygroscopicity of tobacco stem biochar pyrolyzed at different temperatures." Journal of Renewable and Sustainable Energy. Volume 8.1.
7. Yildiz, Zeynep, Selim Ceylan. (2019). "Pyrolysis of tobacco factory waste biomass." Journal of Thermal Analysis and Calorimetry. Volume 136.
8. Christian Mark Pelicano, Nick Joaquin Rapadas, Eduardo Magdaluyo, Jr. (2017). X-ray peak profile analysis of zinc oxide nanoparticles formed by simple precipitation method, AIP Conference Proceedings. Volume1901, 1063, ISSN 1.5010453.
9. Tom Anto,C.R.Rejeesh. (2023). Synthesis and characterization of recycled HDPE polymer composite reinforced with nano-alumina particles, Case Studies in Chemical and Environmental Engineering. Volume72, ISSN 10.1016