Assessing the Removal Efficiency of Microplastics from Water using Electrocoagulation

By

Sehrish Sarwar (2020-NUST-SCEE-BE-Env-350654)
Ahmed (2020-NUST-SCEE-BE-Env-344012)
Mohtashim Noor (2020-NUST-SCEE-BE-Env-335915)

Submitted in Partial Fulfilment of the Requirement for the Degree of

Bachelors

In Environmental Engineering

Institute of Environmental Sciences and Engineering

School of Civil and Environmental Engineering

National University of Sciences and Technology

May 2024

Approval Sheet

t is Certified that the contents and form of the thesis entitled "Assessing the Removal Efficiency of Microplastics from Water Using Electrocoagulation" submitted by Ms. Sehrish Sarwar, Mr. Ahmed and Ms. Mohtashim Noor have been found satisfactory for the requirement of the degree of Bachelor of Environmental Engineering.

Dr. Hira Amjad
Assistant Professor
IESE (SCEE) NUST Islamabad

Supervisor: 7/6/24

Dr. Hira Amjad

SCEE (IESE), NUST

Co-Supervisor: NIDA MAQBOOL 6/7/24

Engr. Nida Maqbool
Assistant Professor
IESE (SCEE) NUST Islamabad

Engr. Nida Maqbool

SCEE (IESE), NUST

Dr. Muhammad Ali Inam
Assistant Professor
HoD Environmental Engineering
SCEE (IESE), NUST
H-12 Islamabad

Ali Inam 07/06/2024

Dr. Muhammad Ali Inam

H.o.D Environmental Engineering

SCEE (IESE), NUST

Prof. Dr. Imran Hashmi
Associate Dean
IESE (SCEE) NUST Islamabad

07/06

Prof. Dr. Imran Hashmi

Associate Dean

SCEE (IESE), NUST

Abstract

Microplastic contamination is a severe environmental problem that must be addressed, especially in developing countries like Pakistan, where there is a dearth of research on its effects on ecosystems and public health. Our initiative suggests an economical and environmentally friendly method for removing microplastic from aquatic habitats, which helps to achieve Sustainable Development Goals (SDGs) 6 (Clean Water and Sanitation) and 12 (Responsible Consumption and Production).

For our experiment, we utilized electrocoagulation (EC), an electrolytic method conventionally used for water and wastewater treatment. EC is well-known for producing coagulants in situ that destabilize and agglomerate microplastics. The intrinsic electrochemical reactions of EC further improve particle removal, providing a low-chemical, size-inclusive, and adaptable technique.

We prepared low-density polyethylene (LDPE), high-density polyethylene (HDPE), and polypropylene (PP) to create microplastics with a particular size range. Using aluminum electrodes, system optimization was accomplished at 12 volts and 100 rpm. The effectiveness of the EC procedure was evaluated in a pilot trial that removed microplastics up to 94%. Following the experiment, the removed flocs and microplastics were recycled sustainably in the formation of bricks, demonstrating the double advantages of our approach: efficient waste management and successful removal of microplastics.

Acknowledgement

We would like to acknowledge and express our sincere appreciation to the following individuals who have played a pivotal role in the successful completion of our final year project:

First and foremost, we owe a great debt of gratitude to our supervisor, Dr. Hira Amjad, whose guidance, expertise, and unwavering support have been instrumental in shaping our project. We are truly grateful for her valuable feedback and constructive input.

We also extend our heartfelt thanks to our co-supervisor, Dr. Nida Maqbool, whose expertise significantly contributed to the quality of our work.

Our sincere appreciation goes to our collaborator, Eco-Bricks, whose support was essential to the success of our project.

We would also like to thank our fellow researchers, Wajeeha, Tashfeen, and Marium, for their insightful discussions and intellectual contributions, which have greatly enriched our understanding of the subject matter.

Special thanks to Ms. Romana for her assistance with the laboratory work, without which this project would not have been possible.

We are grateful to our colleagues and friends for their encouragement, insightful conversations, and unwavering support throughout this challenging journey.

Last but not least, we would like to express our deepest gratitude to our families for their unwavering love, patience, and support. Their belief in our abilities and constant encouragement have been a driving force behind our success.

Table of Contents

List of Figures 8
List of Tables 9
List of Abbreviations 10
Chapter 1: Introduction 11
1. Introduction 11
1.1 Background 11
1.1.2. Plastic pollution in Pakistan 12
1.1.3. Plastic pollution in Oceans 13
1.2. Theory 13
1.2.1. Microplastics 13
1.2.2. Microplastics and marine life 14
1.2.3. Health implications of microplastics 14
1.2.4. Microplastics occurrence in Pakistan 14
1.2.5. Electrocoagulation in Pakistan 15
1.2.6. Electrocoagulation 15
1.3. Problem Statement 17
1.4. Research Objectives 18
1.4.1. Investigating the removal efficiency of MPs from water using electrocoagulation 19
1.4.2. Optimization of the parameters involved in the process of the electrocoagulation 19
1.4.3. Sustainable recycling of removed MPs in bricks 19
1.5. Scope 19
1.5.1. An effective solution for microplastics removal 19
1.5.2. Two size ranges of MPs & shape decided as per the previous studies on the occurrence of MPs in Rawal Lake 20
1.5.3. Water quality improvement 20
1.5.4. Experiments conducted in triplicates 20
1.6. SDG Mapping 17
1.6.1. SDG 3 21
1.6.1.2. Target 3.9 21
1.6.2. SDG 6 21
1.6.3. SDG 12 22
Chapter 2: Literature Review 23
2.1. Electrocoagulation an efficient MPs removal technique 23
2.2. Benefits of using the process of electrocoagulation 23

2.3. Selection of microplastics 24
2.4: Comparison of electrocoagulation with other removal efficiency techniques 24
2.5. Factors affecting the removal efficiency of electrocoagulation. 25
Chapter 3: Methodology 26
3.1. Preparation of MPs 26
3.2. Preparation of MPs solution for removal experiments 27
3.3. Experimental setup 28
3.4. Removal experiment procedure: 28
3.5 Characterization tests 31
3.5.1 PSA (Particle Size Analysis) 31
3.5.2 FTIR (Fourier Transform Infrared Spectroscopy) 31
3.5.3 SEM (Scanning Electron Microscopy) 31
Chapter 4: Results and Discussion 32
4.1. Results of Particle size analysis (PSA) 32
4.1.1 High-density polyethylene (HDPE): 32
4.1.2 Low-density polyethylene (LDPE): 33
4.1.3 Polypropylene (PP): 33
4.2. Results of Fourier Transform Infrared Spectroscopy (FTIR)……… 34
4.2.1 High-density polyethylene (HDPE) 34
4.2.2 Low-density polyethylene (LDPE) 35
4.2.3 Polypropylene (PP) 37
4.2.4 Discussion 38
4.3. Results of Scanning Electron Microscopy (SEM) 39
4.3.1 SEM analysis before electrocoagulation 39
4.3.2 SEM analysis after electrocoagulation 39
4.3.3 Discussion 40
4.4. Analysis of electrocoagulation efficiency for high-density polyethylene (HDPE) microplastics. 41
4.4.1 Overview of experimental conditions 41
4.4.2 Experimental results 41
4.4.3 Interpretation of results 41
4.4.4 Discussion 42
4.5. Analysis of electrocoagulation efficiency for low-density polyethylene (LDPE) microplastics 43
4.5.1 Experimental Results 43

4.5.2 Interpretation of results 43
4.5.3 Discussion 44
4.6. Analysis of electrocoagulation efficiency for polypropylene (PP) microplastics 44
4.6.1 Experimental results 44
4.6.2 Interpretation of results 45
4.6.3 Discussion 45
4.7. Analysis of electrocoagulation efficiency mixed microplastics (MPs) complex 46
4.7.1 Experimental results 46
4.7.2 Interpretation of results 46
4.7.3 Discussion 47
4.7.4 Comparative analysis of removal efficiencies 48
4.8. Critical analysis..........49
4.8.1 Inter-electrode distance and voltage 49
4.8.2 Electrode material selection..........49
4.8.3 Solution pH..........50
4.8.4 Electrolyte composition..........50
4.9. Cost benefit analysis 50
4.9.1 Costs 50
4.9.2 Benefits 50
4.9.3 Reusable filtration alternatives..........51
4.9.4 Reusable filter membranes..........51
4.9.5 Sand filtration setup..........51
4.9.6 Value proposition: sustainable water treatment and microplastic reduction..........51
4.9.7 Industry challenge 51
4.9.8 Our solution: microplastic capture and upcycling 52
4.9. Benefits for petroleum companies..........52
Chapter 5: Future Recommendations and Conclusion..........53
5.1 conclusion 54
5.2 Recommendations 53
  5.2.1 Using other types, size range and concentration of MPs..........53
  5.2.2 Optimization of EC system..........53
  5.2.3 Introduction renewable technologies..........53
  5.2.4 Moving to pilot scale 54
  5.2.4 Examining microplastics in aquatic settings..........54

Chapter 6: Bibliography 58

List of Figures

Figure 1. 1 Sources of microplastics in the environment(Ahmed et al., 2022 13
Figure 1. 2 Plastics in ocean mixing with marine flora (Photograph by Steve De Neef, NAT Geo Image Collection, 2019) 14
Figure 1. 3 Schematic representation of electrocoagulation process (Akhter et al., 2021) .. 17
Figure 1. 4 Representation of microplastics in Rawal lake on the basis of (A) Shape, (B) Size (C) Color and (D) Polymer type (Bashir et al., 2022) 19

Figure 2. 1 Microplastics removal from the Environment(Ahmed et al., 2022) 25

Figure 3. 1 LDPE microbead obtained from laboratory 26
Figure 3. 2 LDPE pallet prepared in laboratory and stainless steel filer 27
Figure 3. 3 LDPE MPs 27
Figure 3. 4 LDPE solution prepared for experimentation 28
Figure 3. 5 Lab scale EC setup 29
Figure 3. 6 LDPE solution after 16 hours settling 31
Figure 3. 7 Filter paper left to dry for 24 hours 32
Figure 3. 8 Removed MPs and Flocs 33

Figure 4. 1 PSA graph of HDPE 34
Figure 4. 2 PSA graph of LDPE 35
Figure 4. 3 PSA graph of PP 35
Figure 4. 4 FTIR Analysis of pure HDPE microplastics generated in laboratory 37
Figure 4. 5 Reference FTIR Spectrum for HDPE Microplastics (Prajapati et al., 2021) 37
Figure 4. 6 FTIR Analysis of pure LDPE microplastics generated in laboratory 38
Figure 4. 7 Reference FTIR Spectrum for LDPE Microplastics (Prajapati et al., 2021) 39
Figure 4. 8 FTIR Analysis of pure PP microplastics generated in laboratory 40
Figure 4. 9 Reference FTIR Spectrum for PP Microplastics (Prajapati et al., 2021) 40
Figure 4. 10 SEM results of plastic before Electrocoagulation 42
Figure 4. 11 SEM results of plastic after Electrocoagulation 42
Figure 4. 12 Comparative removal efficiency of all experiments 52

List of Tables

Table 1. 1 Results of HDPE 44
Table 1. 2 Results of LDPE.. 46
Table 1. 3 Results of PP 48
Table 1. 4 Results of MP complex 50

List of Abbreviations

Electrocoagulation	EC
Microplastic	MP
Low-density polyethylene	LDPE
High-density polyethylene	HDPE
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. The focus of our study was the determination of removal efficiency of microplastics by using the process of electrocoagulation. This chapter also discusses the process and mechanism of electrocoagulation in detail, including its comparison with other removal efficiency techniques that are being used nowadays for microplastics removal.

1.1 Background

In recent years, plastic production has been increased. Many people have started to use things made of plastic because they are cheap in comparison to all the other materials available on the market. Due to its reputation of being readily available, many manufacturing, packaging, construction, and consumer goods industries tend to rely on plastics. The usage of plastics continues to grow in our lives; therefore, it is being produced in significant quantities. However, plastic consumption contributes to pollution. Once the items made of plastics are no longer required these are dumped into landfills and often ends up in oceans.

Additionally, plastics can take hundreds of years to decompose, leading to long-term environmental degradation. Moreover, plastic particles can enter the food chain, posing health risks to humans and animals. Overall, excessive plastic consumption is detrimental to human health and causes environmental concerns. Plastic consumption is a major issue all around the world and third world countries like Pakistan shows more concerns related to plastic consumption. As it is an issue that’s often get neglected by the countries of Pakistan.

1.1.1. Plastic waste and population

Plastic consumption increases with the growing population worldwide and results in increased quantities of plastic waste. There are various plastic waste management strategies; however, the present management progress is not sustainable and plastic waste dumping in landfills is still the most employed strategy. Being nonbiodegradable, plastic waste dumping in landfills creates several environmental and human health problems. Numerous research studies have been conducted recently to determine safe and ecologically beneficial methods of plastic waste handling (Huang et al., 2022).Fig 1. Shows some of the sources of microplastics in environement.

Figure 1. 1 Sources of microplastics in the environment (Ahmed et al., 2022)

1.1.2. Plastic pollution in Pakistan

The widespread use of plastics has led to both convenience and environmental degradation, with safe disposal becoming a significant challenge. Pakistan, like many other countries, faces health and environmental hazards due to extensive plastic usage.

The country's irrigation system, one of the largest gravity flow systems globally, is particularly affected by plastic pollution. Plastic waste originating from various activities, including tourism, agriculture, and industry, finds its way into streams and rivers, eventually reaching irrigation infrastructure (Mukheed & Khan, 2021).

1.1.3. Plastic pollution in Oceans

Plastics of various sizes are present in all ocean regions, accumulating primarily in subtropical gyres. Prevailing winds and surface currents transport plastic pollution globally, with long-term transport leading to accumulation in ocean basins. Plastic Pollution in the World's Oceans: More than 5 trillion Plastic Pieces Weighing over 250,000 Tons Afloat at Sea (Andrady, 2011). Studies indicate that approximately 8 million tons of plastic waste is deliberately deposited into the ocean worldwide. It takes hundreds of years for a single-use plastic bag to decompose. Wrappers account for nearly 30 percent of waste contributions, while plastic containers and bottles contribute around 15 percent to this total. Figure 1 shows plastics in oceans. Fig 2. Shows the plastics in ocean mixing with marine flora.

Figure 1. 2 Plastics in ocean mixing with marine flora (Photograph by Steve De Neef, NAT Geo Image Collection, 2019)

1.2. Theory

This project aims to remove microplastics from water. To grasp the removal process effectively, it's crucial to delve into the context of the issue and connect the prevalence of microplastics, their health and environmental consequences, with the project's goals.

1.2.1. Microplastics

Microplastics are referred to the plastic particles with size smaller than 5mm (Arthur et al., 2009; Cole et al., 2009). Microplastics in water is becoming a major issue globally. Like other environmental threats like climate change and persistent organic pollutants, plastic debris reflects humanity's ability to impact the environment on a global scale. Some researchers argue that marine plastic contamination meets criteria for a planetary boundary threat due to its irreversible and widespread nature. Microplastics take various forms, including spheres, fragments, and fibers, most of which originate from the breakdown of larger plastics. They further degrade into even smaller debris known as microplastics (Hale et al., 2020).

1.2.2. Microplastics and marine life

Weathering-related processes, particularly in beach environments, are a significant contributor to microplastic generation. Although microplastics make up a small fraction of sea water particulates. Plankton form the foundation of marine food webs, threats to these organisms can have significant and widespread consequences in the world's oceans (Andrady, 2011).

1.2.3. Health implications of microplastics

Microplastics research is rapidly evolving, delving into potential impacts on human health. Studies suggest that microplastics pose chemical, microbial, and particle hazards that can interact with the human body through various exposure pathways like ingestion, inhalation, or skin contact (Yang et al., 2022). Microplastics are proved to 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

Microplastic pollution poses a growing environmental concern, with most research focusing on marine environments. However, there is limited data on microplastic presence in freshwater, particularly in Pakistan (Irfan et al., 2020). Microplastics (MPs), recognized as global contaminants, have been increasingly detected in various environments. However, limited evidence exists regarding their potential to accumulate and magnify along the food chain. Higher MP levels were observed in all samples from River Ravi, ranging from 3.0 ± 1.58 MP items in water to 15.20 ± 3.35 MP items in air (Qaiser et al., 2023). 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 *(*Bashir etal, 2022*).*

1.2.5. Electrocoagulation in Pakistan

Due to increasing water scarcity in Pakistan, there's a growing need to utilize treated wastewater, especially for landscape irrigation and planting, to supplement limited water resources. Therefore, for our project we have focused on the process of electrocoagulation (EC) process to remove microplastics from drinking water, aiming to meet international standards for water that is drinkable. The impact of different operational factors such as treatment duration, current intensity, and electrode spacing was assessed to optimize treatment effectiveness (Saleem et al., 2011).

1.2.6. Electrocoagulation

Electrocoagulation is a water treatment process that involves the destabilization and removal of suspended particles, colloids, and pollutants from water by applying an electric current. Typically, the electrocoagulation reactor is comprised of electrodes and an electrolytic cell. Electrocoagulation operates by directing an electric current through an electrolytic cell, leading to the oxidation of metal compounds at the anode. Fig 3. shows the schematic representation of electrocoagulation process. This process results in the release of highly charged metal ions, which then interact with hydroxide ions and are carried by hydrogen and oxygen produced through water electrolysis. Simultaneously, at the cathode, water molecules ionize, forming OH− and hydrogen gas bubbles (W. Tang et al., 2022). The cathodes release negatively charged hydroxide ions, which bind to the positively charged ions, thereby creating colloidal flocs. Through the hydrolysis process, metal cations form positively charged hydrolysis products that absorb negatively charged microplastics and convert the cations to become amorphous (W. Tang et al., 2022).

The electrochemical reactions occurring at anode are summarized as follows:

- **At the anode:**

$$M(s) \rightarrow M(aq)n+ + ne- \qquad (1)$$

$$2H2O(l) \rightarrow 4H++O2(g) + 4e- \qquad (2)$$

The electrochemical reactions occurring at cathode are summarized as follows:

- **At the cathode:**

$$M(aq)n+ + ne- \rightarrow M(s) \qquad (3)$$

$$2H2O(l) + 2e \rightarrow H2(g) + 2OH- \qquad (4)$$

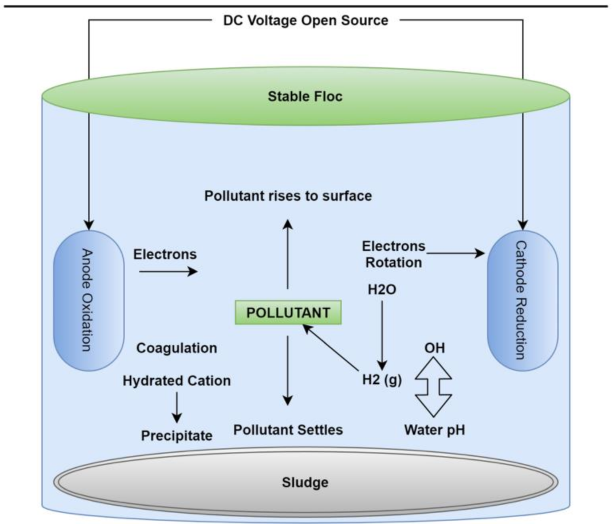


Figure 1. 3 Schematic representation of electrocoagulation process (Akhter et al., 2021)

1.3. Problem Statement

Microplastics, which are small plastic particles less than 5 millimeters in size, have emerged as persistent pollutants that pose significant concerns regarding their impact on human health and the environment. These tiny particles can originate from various sources such as the breakdown of larger plastic debris, synthetic clothing fibers, or microbeads used in personal care products. Due to their small size and widespread distribution, microplastics have the potential to accumulate in ecosystems, including water bodies, soil, and even the air.

Limited studies have been conducted to assess the presence and extent of microplastic pollution in Pakistani environments, including rivers, lakes, and coastal areas. This knowledge gap presents a significant challenge in understanding the scope of microplastic pollution and implementing effective mitigation strategies.

Furthermore, traditional water treatment and waste management technologies in Pakistan are not specifically designed to address the removal of microplastics. Conventional wastewater treatment plants and solid waste management systems may not effectively capture or remove microplastics from the environment. As a result, these persistent pollutants can continue to accumulate in water bodies and soil, posing risks to aquatic life, wildlife, and potentially human health. Fig 4. shows microplastics shape, color and type in Rawal Lake.

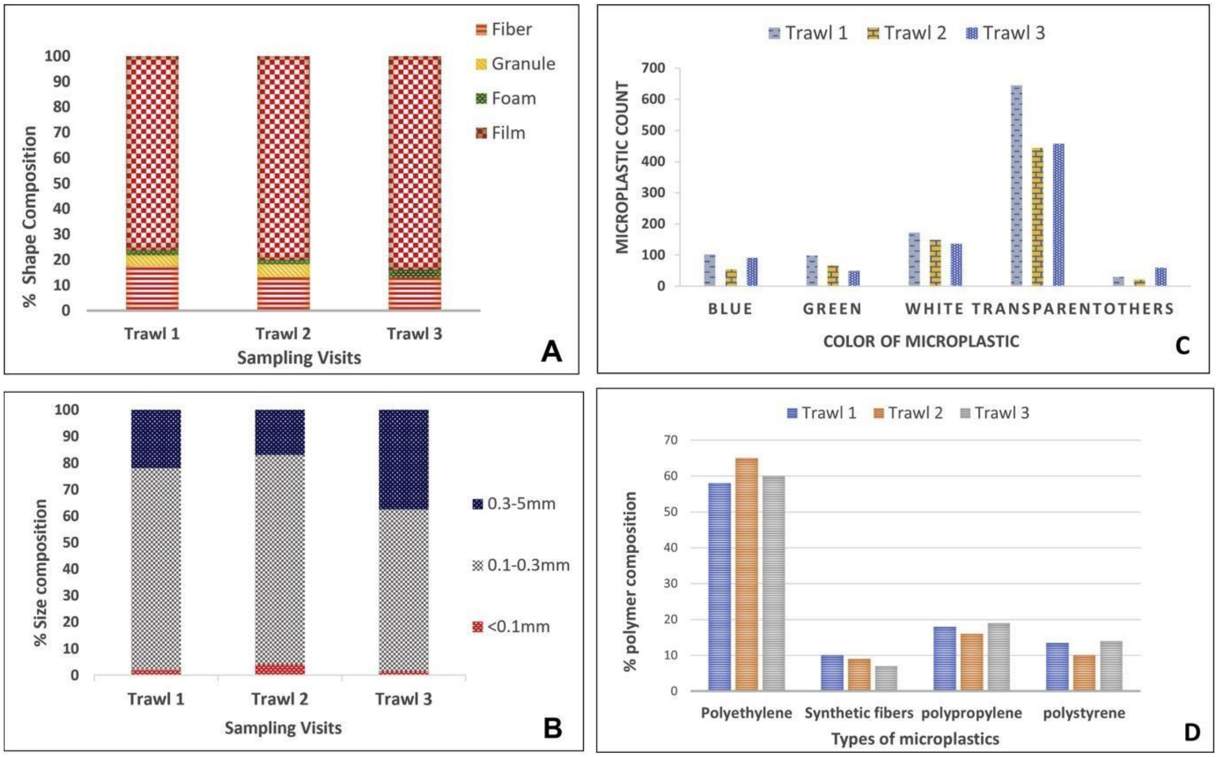


Figure 1. 4 Representation of microplastics in Rawal lake on the basis of (A) Shape, (B) Size (C) Color and (D) Polymer type (Bashir et al., 2022)

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:

- To establish a cost-effective and sustainable electrocoagulation prototype for MP removals.

- To investigate the removal efficiency of MPs from water using electrocoagulation.
- To ensure the sustainable recycling of removed MPs in bricks.

1.4.1. Investigating the removal efficiency of MPs from water using electrocoagulation

We have designed a prototype system that utilizes electrocoagulation to remove microplastics from water. Using the process of Electrocoagulation is not only economically viable but is also environmentally sustainable in its operation.

1.4.2. Optimization of the parameters involved in the process of the electrocoagulation

Our project involved conducting experiments and doing analyses to determine the efficiency of electrocoagulation in removing microplastics from water. It involves assessing factors such as treatment time, applied voltage, electrode material, and water characteristics to optimize the removal process and understand its effectiveness in different scenarios.

1.4.3. Sustainable recycling of removed MPs in bricks

Once microplastics are removed from water using electrocoagulation, they are sent to Eco Ricks for recycling. By incorporating the removed microplastics into bricks, they can be effectively reused in construction materials, thereby preventing their re-entry into the environment, and contributing to sustainable waste management practices.

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 our study quantifies the effectiveness of electrocoagulation in reducing microplastic contamination, thereby contributing to the development of effective solutions for mitigating microplastic pollution.

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

A study conducted on Rawal Lake investigates the presence and quantity of microplastics within its waters. The predominant type of microplastics found in the lake's tributaries is polyethylene. Irregularly shaped fragments were the most frequently observed form. The concentration of microplastics detected ranged from approximately 6.4±0.5 particles per cubic meter to 8.8±0.5 particles per cubic meter (Bashir et al., 2022).

1.5.3. Water Quality Improvement

The project aims to contribute valuable insights into the potential of electrocoagulation as a sustainable and effective method for improving water quality through microplastic removal.

1.5.4. All experiments will be lab-based with triplicates.

By conducting rigorous laboratory-based experiments with triplicates, this project aims to provide valuable insights into the efficacy of electrocoagulation for microplastic removal, contributing to the development of sustainable water treatment technologies.

1.6.SDG Mapping

Sustainable Development Goals (SDGs) are a set of 17 goals that were adopted by all United Nations Member States in 2015 as part of the 2030 Agenda for Sustainable Development. They serve to end poverty, protect the planet, and ensure that all people enjoy peace and prosperity. Each goal stands for a different issue and aims at achieving sustainability in that veryaspect.

These goals play an important part in today’s world to secure an economically sound future. Our project primarily aligns with Sustainable Development Goal 6, which focuses on ensuring access to clean water and sanitation. Additionally, it contributes to the SDG 12 by encouraging responsible consumption and production practices.

1.6.1. SDG 6s

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

1.6.1.1. SDG 6.3

This target seeks to improve the quality of water. This could be achieved 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 also relates to the issue of plastics and microplastics found in the ocean. This contamination caused decreases in water quality. Our project also relates to improving the quality of drinking water by removing microplastics.

1.6.2. SDG 12

SDG 12 focuses on responsible consumption and production practices. It promotes sustaining production patterns and consumption habits. It also addresses issues relating to pollution, climate crises and biodiversity loss.

Chapter 2: Literature Review

2.1. Electrocoagulation an efficient MPs removal technique

Electrocoagulation (EC) technology was found to have a significant removal efficiency (91.7%) for microplastics in wastewater treatment (Shen et al., 2022). The basic EC unit consists of an electrolytic cell with its anode and cathode as electrodes externally connected to the DC power supply. EC is an electrolytic process in which a metal anode is immersed in the electrolyte solution to generate cations by applying a current (Zaied et al., 2020). Similar to the coagulation process, the EC process is mainly divided into three stages to remove pollutants: (1) the dissolution of anode to produce metal cations in situ; (2) the metal cations hydrolyzed to form the mononuclear and polynuclear hydroxides, as “micro-coagulant”, flocculating the suspended pollutants to form flocs; (3) the hydrolysis of water into H2 on the cathode, so that the slight and heavy flocs can be removed via flotation and precipitation, respectively (Ingelsson et al., 2020). More fibers tended to be removed than fragments, viz. 92% fibers removed versus 88% fragments. Many studies have also demonstrated that specific polymers were preferentially removed, viz. PET > LDPE > PP > PA. Further analysis indicated that the electrocoagulation treatment affected microplastic polymers physically (Senathirajah et al., 2023).

2.2. Benefits of using the process of electrocoagulation

Electrocoagulation treatment has multiple benefits including environmental compatibility, low capital cost, energy efficiency, cost-effectiveness, and versatility. It is easily scaled up if required by adding parallel units (Shen et al., 2022). As pollutants are removed without the addition of chemicals, the need to transport, handle or store chemicals is eliminated, which generates additional benefits of cost savings, automation, convenient operations and safer operator health and wellbeing. Furthermore, compared with coagulation and flocculation treatment, electrocoagulation produces less sludge that is more hydrophobic, i.e. less dewatering necessitated (Lu et al., 2021; Shen et al., 2022;

W. Tang et al., 2022). Additionally, hydroxyl radicals generated by water oxidation produce compounds such as hydrogen peroxide that can oxidise toxic species into non-toxic species (Lu et al., 2021).

2.3. 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 (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). 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).

2.4. Comparison of Electrocoagulation with other removal efficiency techniques

There are various technologies that exist for removing microplastics, each with its own advantages and limitations. There are physical methods including adsorption, membrane filtration, and sedimentation that offer cost-effective solutions.

There are many chemical methods such as coagulation, agglomeration, and photocatalytic degradation. Moreover, these methods require additional chemicals and may lead to secondary pollution. Photocatalytic degradation, although utilizing solar energy, lacks selectivity for microplastic types and can generate secondary pollution. Designing efficient photocatalysts that are easily separable, recoverable, and reusable is crucial for cost-effective and sustainable treatment. Biological methods, relying on activated sludges, biological degradation, and ingestion by organisms, offer low operating costs and scalability but are relatively inefficient and depend on organism species and treatment conditions. Despite this, biological strategies have advantages such as large-scale feasibility and flexibility for pollutant removal. The key challenges lie in identifying suitable microbes for microplastic removal and tracking down byproducts.

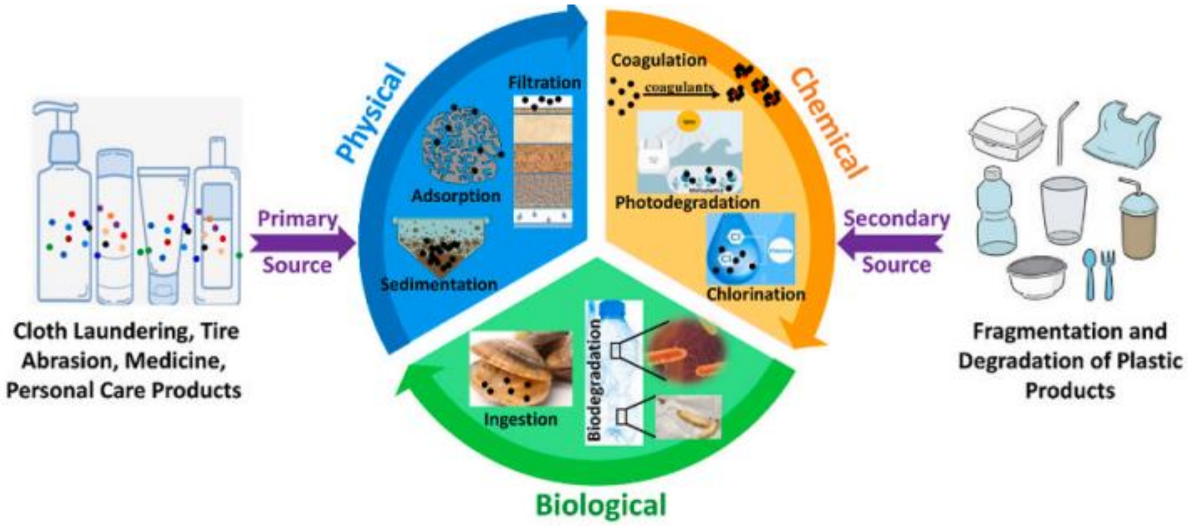


Figure 2. 1 Microplastics removal from the Environment (Ahmed et al., 2022)

2.5. Factors affecting the removal efficiency of Electrocoagulation.

There are many factors that affect the process of Electrocoagulation such as electrode materials, current density, supporting electrolyte, and pH. These factors play crucial roles in determining the efficiency and effectiveness of the MP removal mechanism.

The conductivity of the solution has a crucial impact on the EC operations. The conductivity of the solution is linearly related to the concentration of the supporting electrolyte. To optimize operating parameters when using synthetic water for EC testing, it is often necessary to add supporting electrolytes to improve current efficiency. Electrolytes commonly used in the EC process mainly include sodium sulfate (Na_2SO_4) and sodium chloride (NaCl). Studies revealed that neutral pH achieves a better removal efficiency of MPs due to neutral pH favoring the generation of Al coagulants. The Al coagulants formed at neutral pH are useful for trapping and adsorption of MPs (Ahmed et al., 2022). Studies also show that the removal efficiency of microplastics by electrocoagulation with Al anode is better than that of with Fe anode (Shen et al., 2022)

Chapter 3: Methodology

3.1 Preparation of MPs:

In the laboratory, we employed a systematic approach to synthesize high-density polyethylene (HDPE), low-density polyethylene (LDPE), polypropylene (PP) and complex sample.

LDPE synthesis:

- After obtaining LDPE pallets, the initial step involved the preparation of MPs.

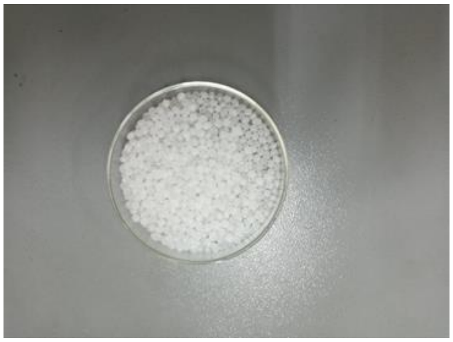


Figure 3. 1 LDPE microbead obtained from Toxicology laboratory

- The pallets were heated to a specific temperature and melted. The melted pallets were then moulded into a square and allowed to cool so that they would solidify. The MPs were then meticulously crushed with a stainless-steel file. This deliberate crushing procedure ensured the production of various MPs of different sizes, facilitating the following processing and analysis.

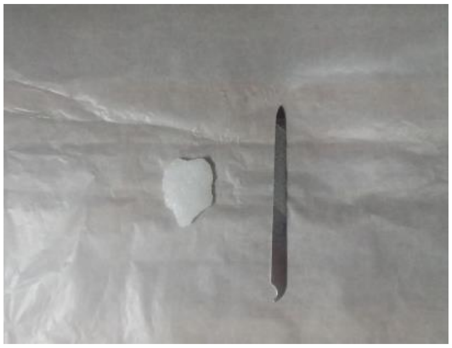


Figure 3. 2 LDPE pallet prepared in laboratory and stainless steel filer

- Following the precise crushing of the microplastics, we passed the MP through two sieve sizes of < 150 μm and < 425 μm. This step was crucial to ensure that we obtained MPs within a specific size range for our experiments. We received a particular range of MPs of different sizes for the removal experiments.

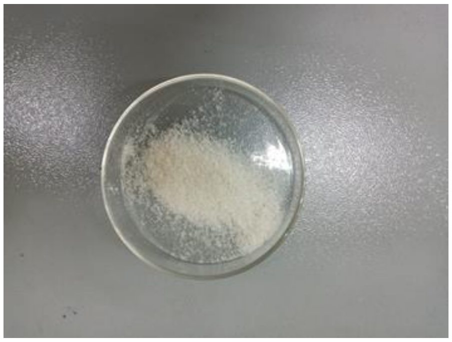


Figure 3. 3 LDPE MPs

- In order to verify this size range, we performed a particle size analyser on the laboratory generated MPs.

For HDPE and PP MPs synthesis we repeated the above-mentioned steps.

3.2 Preparation of MPs Solution for Removal Experiments:

Preparation of LDPE solution for experimentation:

- We took a 100 ml beaker and filled it with distilled water.
- Then, we added 0.5g of LDPE MPs to the 100 ml breaker.
- In order to form a uniform suspension, 50 mg of Sodium dodecyl sulfate was also added to the same beaker.

- To promote further homogeneity, we used the sonication technique for 20 minutes at 20°C.
- Then, we took a separate 1-liter beaker and filled it with 850 ml of distilled water.
- 0.5g NaCl was added to the distilled water to increase the conductivity.
- Subsequent pH and conductivity of the distilled water were measured to ensure it was within the desired range.
- Then, we transferred the MP solution to this 1-liter beaker.
- Lastly, the beaker was filled up to the 1000 ml mark with distilled water.

Figure 3. 4 LDPE solution prepared for experimentation

The same steps were repeated to create HDPE, PP and MP complex solution for experimentation.

3.3 Experimental setup:

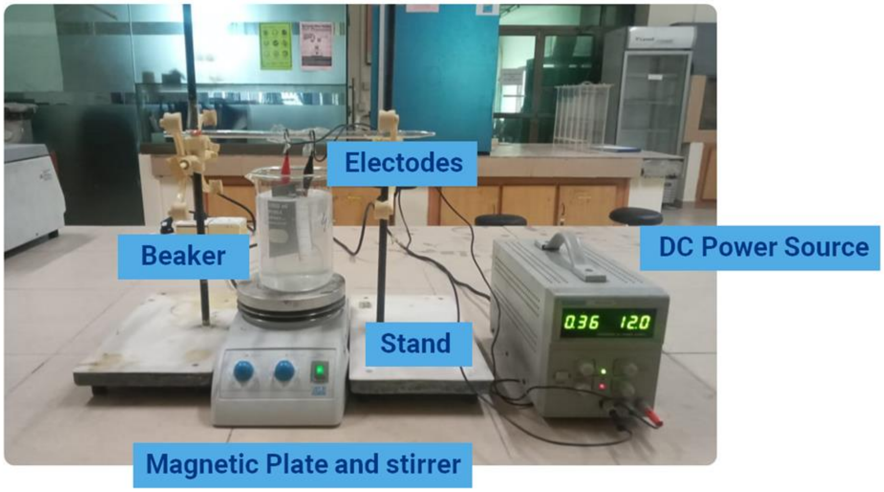


Figure 3. 5 Lab scale EC setup

Before every experiment, the beaker was rinsed with tap and distilled water, and the sample was collected afterward. A pair of aluminium electrodes were used for every experiment and wired to an external DC power supply. The beaker was placed on a magnetic plate, and a magnetic stirrer was placed in the beaker along with the sample.

3.4 Optimization of system:

In order to optimize the system for MP removal, the parameters were selected and optimized based on existing research. The parameters used for the optimization of the system are:

1) Voltage and inter-electrode distance
2) pH
3) Mixing Voltage

3.4.1 Voltage and inter-electrode distance

The EC system performs best when the inter-electrode distance is between 1 and 3 cm because it balances the voltage drop and electrical resistance. A shorter distance can result in reduced resistance, raising the current and improving removal efficiency. However, it also increases the possibility of overusing electricity and short-circuiting. On the other hand, a more significant distance results in higher resistance and voltage drop, which may lessen the interaction between the coagulant species and the contaminants and, hence, lower removal efficiency (Liu et al., 2023b).

3.4.2 pH

The initial pH in the EC process is a critical factor that significantly affects the elimination of MPs. The type of flocs formed is directly linked to the solution's pH, as we've discussed earlier. When the initial pH of the solution is below 3, the dissolved metal ions primarily exist as soluble ions and cannot form insoluble solid coagulants. Metal ions are restricted to forming weak coagulants in robust alkaline solutions (more than 9). This leads to a decline in MP removal efficiency in the EC process. However, our academic research highlights that maintaining a neutral pH can enhance MP removal efficiency by promoting the production of Al coagulants. These Al coagulants, formed under neutral pH conditions, are not just beneficial, but highly effective for adsorption and ensnaring, providing a reliable solution for MP removal (Liu et al., 2023b).

3.4.3 Mixing speed

The electrocoagulation process relies on proper mixing, facilitated by stirring speed between 80 and 300 rpm, to enhance the interaction between microplastics and coagulant species (Liu et al., 2023b). This interaction is crucial for effective removal of microplastics, but excessively high stirring speeds can disintegrate the developing flocs and lower removal effectiveness.

3.3 Removal Experiment Procedure:

For LDPE:

1. The prepared LDPE solution beaker was carefully positioned onto the magnetic plate.
2. To facilitate turbulence and agitation of MPs, we set the magnetic stirrer speed to 100 rotations per minute (rpm).
3. To optimize the electrocoagulation process parameters for efficient MP removal, the inter-electrode distance was meticulously set to 2 cm. This distance was chosen to ensure that the electric field was evenly distributed across the solution, promoting uniform coagulation of the MPs.
4. A consistent 12 volts was supplied using a DC power supply during the 60-minute electrocoagulation process. The purpose of this process was to remove the MPs from the solution by causing them to coagulate and settle at the bottom of the

beaker.

5. Following the completion of EC, the beaker was carefully removed from the setup and transferred to a designated shelf, where the solution was left undisturbed to settle for 16 hours (Subair,et al., 2024).

Figure 3. 6 LDPE solution after 16 hours settling

6. Then, a vacuum pump was utilized to extract 100 ml of representative water sample from the settled solution in a volumetric flask. It was ensured that the extraction was performed at a consistent depth, maintaining a 2 cm mark from the top of the solution (Subair et al., 2024).
7. We then passed the sample through a filtration assembly, and a 0.45-micron pore-size filter paper weighing 0.75g was used to ensure the efficient removal of MPs from the sample. This specific filter paper size was chosen to ensure that only the microplastics, and no other particles, were retained in the filter.
8. Subsequently, the filter paper was left to dry for 24 hours to ensure the complete removal of moisture (Subair et al., 2024).

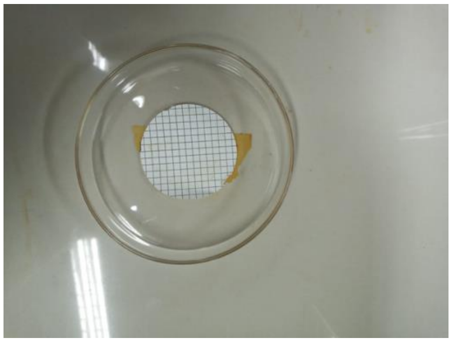


Figure 3. 7 Filter paper left to dry for 24 hours

9. After drying, the filter paper was weighted using a microbalance.
10. We then calculated the efficiency using the formula below. This formula was used to determine the percentage of microplastics that were successfully removed from the solution during the electrocoagulation process.

$$\frac{W_f - W_i}{W_f} \times 100$$

11. The remaining solution in the beaker was also filtrated using a normal filter paper sheet so that the flocs settled below could be recycled. We repeated the same procedural steps for HDPE, PP, and complex solution.

Each experiment was conducted with a meticulous selection of 0.5g of MP. We ensured the MP complex for a single experiment was a balanced blend of three distinct plastics—33% high-density polyethylene (HDPE), 33% low-density polyethylene (LDPE), and 33% polypropylene (PP). This careful selection resulted in an MP solution with a total weight of 0.5g, ensuring the validity of our experiment.

In our experimentations, we conducted four trials on a single microplastic type. In order to ensure the reliability and validity of our results, we employed a robust experimental design with three replicates in addition to an essential blank control. We prepared the microplastic solution for the control case according to a particular protocol, after which we did not use any electrocoagulation intervention. Instead, we let it settle spontaneously for 16 hours. This unique method ensured that the control group offered an unambiguous baseline—free from outside interference—against which the effects of EC could evaluated. Following the settling, we repeated the same steps to investigate the removal efficiency of control.

After all the experiments were concluded, the collected MPs and floc were sent to Ecobricks so that they could be incorporated into their sustainable and eco-friendly bricks.

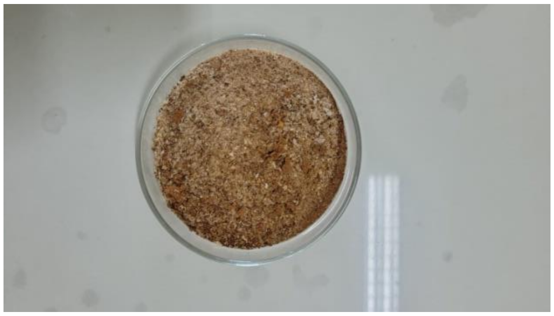


Figure 3. 8 Removed MPs and flocs

3.5 Characterization tests:

3.5.1 PSA (Particle Size Analysis)

We used Particle size analysis to ascertain MPs' size distribution and range in a particular sample. This analysis entails calculating the size distribution profile and determining the particles' diameters in a material. Verifying the size ranges of MPs was important.

3.5.2 FTIR (Fourier Transform Infrared Spectroscopy)

FTIR analysis was performed in the USPCASE lab to verify the quality of the HDPE, LDPE, and PP microplastics made in the lab for use in subsequent experimentation.

3.5.3 SEM (Scanning Electron Microscopy)

The powerful imaging method known as scanning electron microscopy (SEM) is used to get high-resolution images of a sample's surface morphology, allowing for in-depth analysis at the micro- and nanoscale levels. Two samples were tested under a scanning electron microscope. The first sample was raw MP generated in the laboratory. The second sample was tested on MP collected on filter paper after electrocoagulation. This analysis was crucial to verify the size and shape of the MPs before and after the removal process.

Chapter 4: Results and Discussion

4.1 Results of Particle Size Analysis (PSA)

The particle size distribution of the microplastics utilized in the experiments was rigorously analyzed using Particle Size Analysis (PSA). This analytical technique was essential for confirming that the sizes of the microplastic particles fell within the target range specified for our study, which was between 105 µm and 425 µm. This size range was chosen based on preliminary studies that suggested optimal interaction sizes for the electrocoagulation process to effectively remove microplastics from water.

4.1.1 High-Density Polyethylene (HDPE):

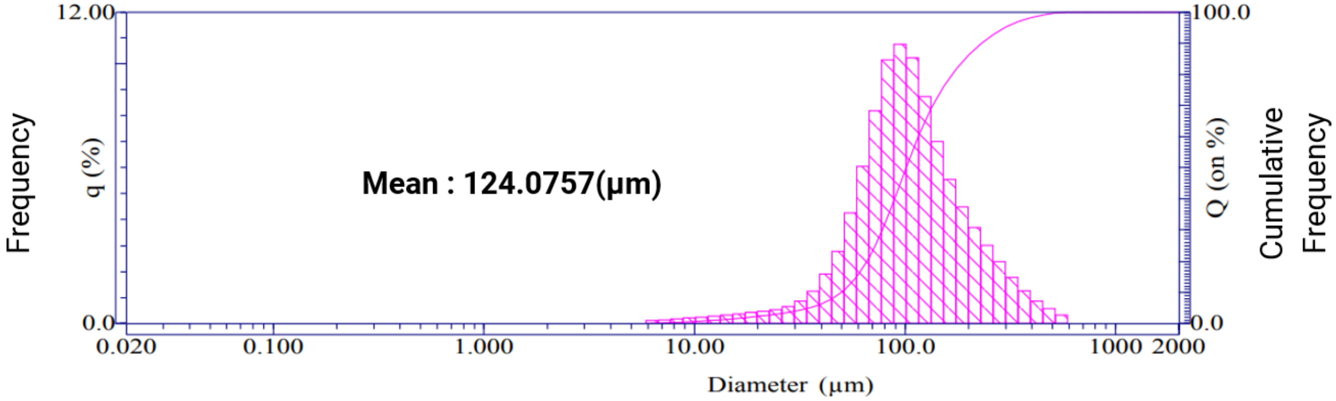


Figure 4. 1 PSA graph of HDPE

The particle size analysis for HDPE revealed a mean particle size of 124.0757 µm, comfortably situating within the targeted range of 105 µm to 425 µm. This narrower distribution indicates a high degree of uniformity in particle size, which is critical for ensuring consistent treatment efficacy throughout the electrocoagulation process. The consistency in size can significantly enhance the predictability and reliability of the removal outcomes.

4.1.2 Low-Density Polyethylene (LDPE):

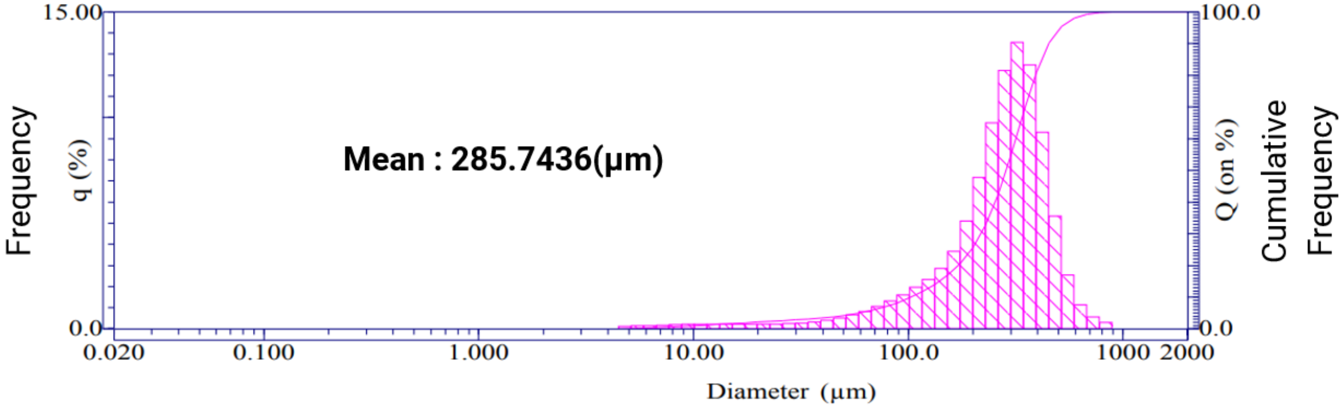


Figure 4. 2 PSA graph of LDPE

The particle size distribution for LDPE demonstrated a mean size of 285.7436 μm. This finding is significant as it approaches the upper limit of our targeted size range, potentially affecting the dynamics of electrocoagulation interaction. The broader spread in the size distribution might suggest variable interaction times and efficiencies, which could be critical for optimizing process parameters.

4.1.3 Polypropylene (PP):

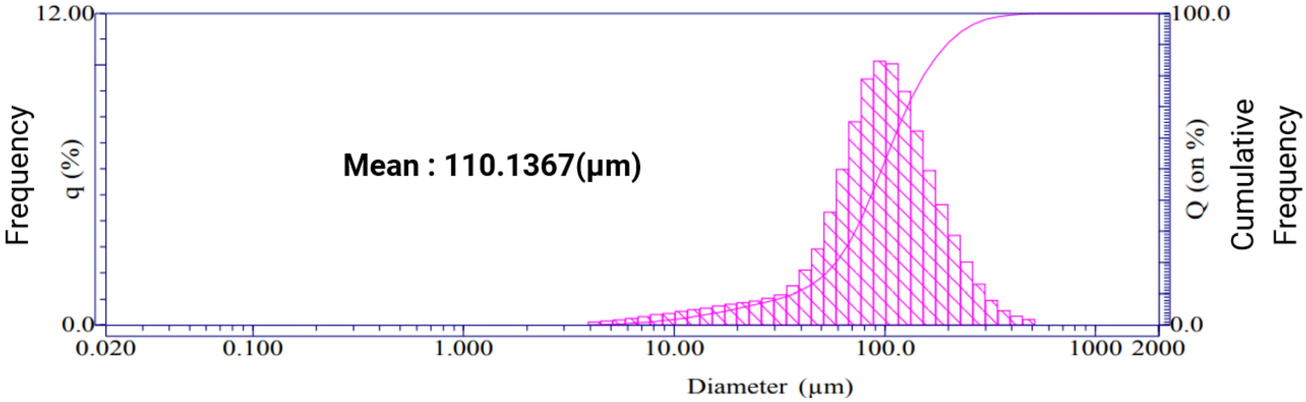


Figure 4. 3 PSA graph of PP

Polypropylene showed a mean particle size of 110.1367 μm. Positioned just above the lower threshold of our size range, the finer particles of PP might enhance the process by increasing the surface area available for interaction with the coagulating agents. This increased surface area can be advantageous, potentially leading to more effective microplastic aggregation and subsequent removal.

These results affirm that the microplastics prepared and utilized in our study adequately meet the size criteria established in the methodology. The consistency across different types of plastics ensures that the experimental findings are applicable across a similar spectrum of microplastic pollutants found in water bodies. Ensuring that the particle sizes fall within this defined range is crucial as it affects the interaction with coagulants during the electrocoagulation, directly impacting the removal efficiency and reliability of the process.

The adherence to the specified size range also aligns with established research that emphasizes the importance of particle size in treatment processes. Like the findings in the referenced thesis, where specific particle sizes were targeted for enhanced adsorption efficiency, our study leverages the controlled particle size to optimize the electrocoagulation process, aiming for maximum removal efficiencies.

4.2 Results of Fourier Transform Infrared Spectroscopy (FTIR)

The Fourier Transform Infrared Spectroscopy (FTIR) analysis was conducted to verify the chemical composition and purity of the microplastics used in our experiments. The FTIR spectra provides a detailed characterization of the types of bonds and functional groups present in the polymer structures of our microplastics. Below, we present the results and comparisons for each type of plastic tested.

4.2.1 High-Density Polyethylene (HDPE)

Graph A:

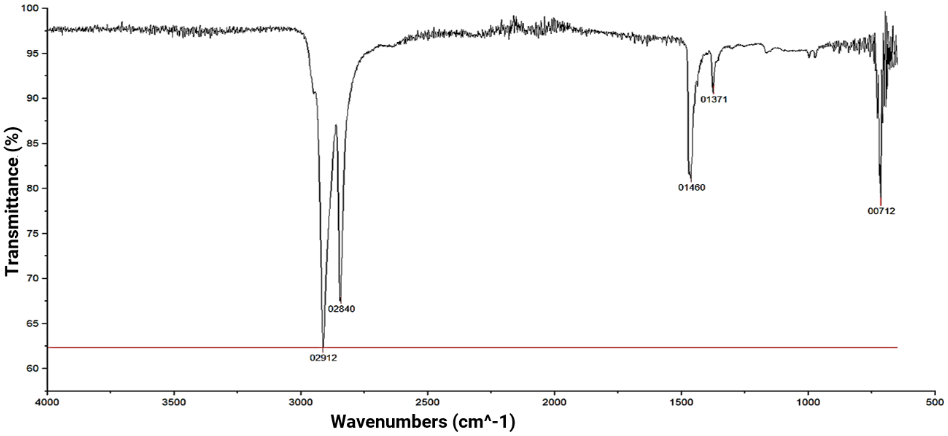
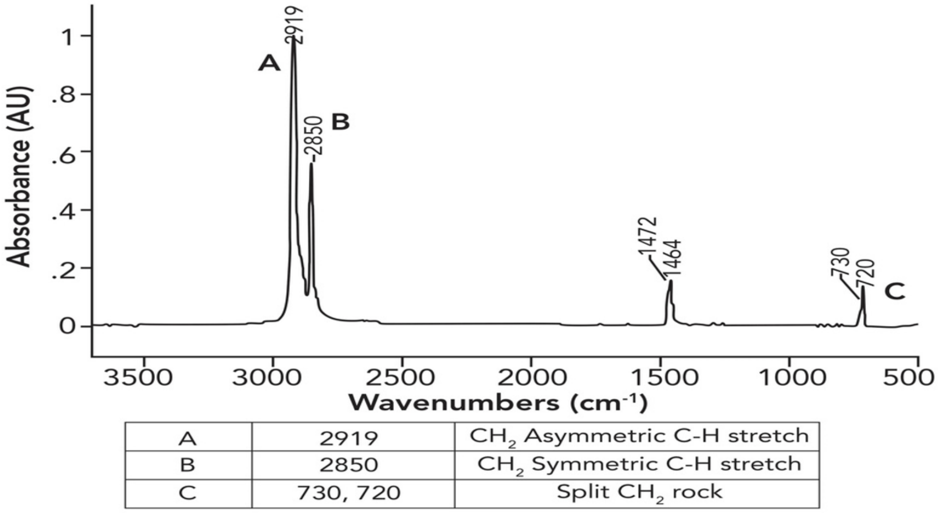


Figure 4. 4 FTIR Analysis of pure HDPE microplastics generated in laboratory



A	2919	CH_2 Asymmetric C-H stretch
B	2850	CH_2 Symmetric C-H stretch
C	730, 720	Split CH_2 rock

Figure 4. 5 Reference FTIR Spectrum for HDPE Microplastics (Prajapati et al., 2021)

The FTIR spectrum of HDPE shows characteristic peaks at:

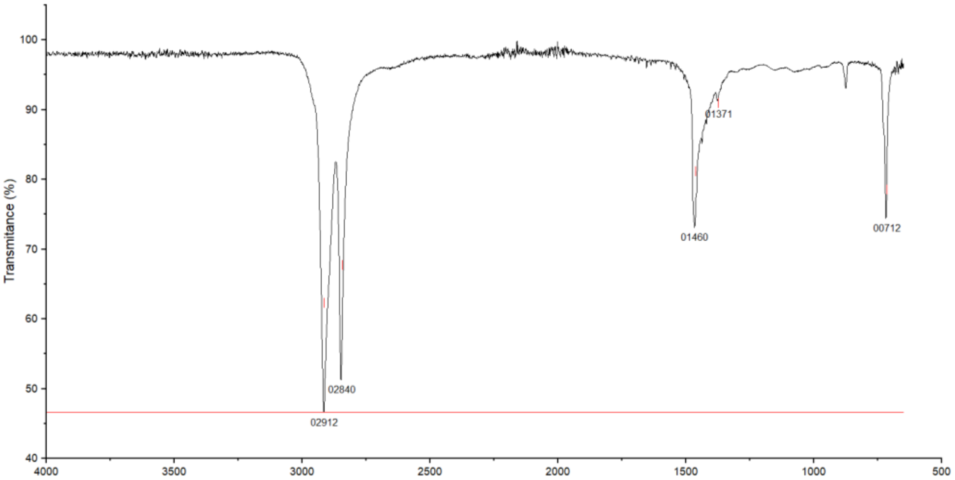
- **2912 cm−1−1** and **2840 cm−1−1**, which correspond to the asymmetrical and symmetrical stretching vibrations of CH_2 groups, respectively.

- **1460 cm−1−1**, indicating the bending vibrations of CH_2.
- **712 cm−1−1**, associated with the rocking vibrations of CH_2 groups.

These peaks are closely aligned with the reference spectrum for HDPE, confirming the material's purity and suggesting that the HDPE used was free from significant contamination. The presence of these specific peaks, which match those found in standard references for pure HDPE, validates our experimental setup and the reliability of our subsequent findings regarding the electrocoagulation process (Prajapati et al.,2021).

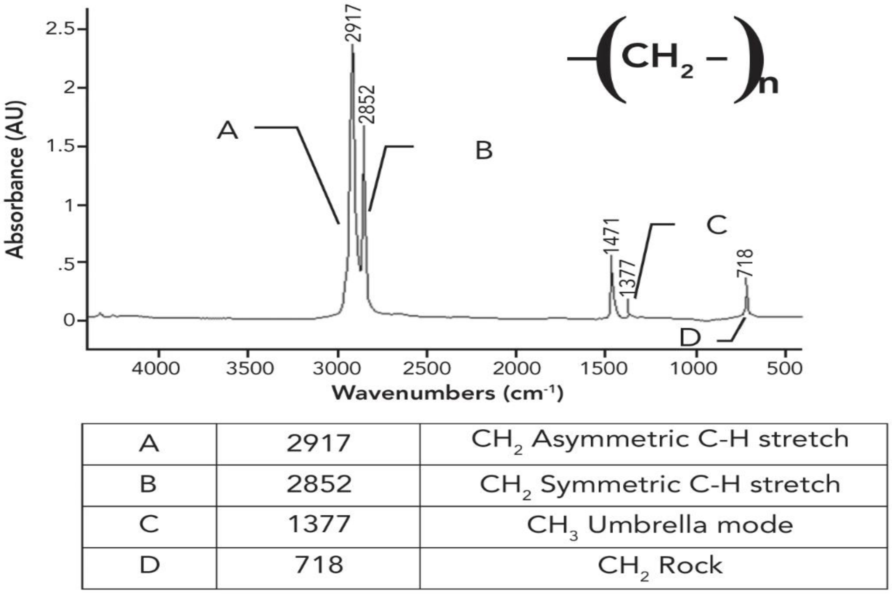
4.2.2 Low-Density Polyethylene (LDPE)

GRAPH B:



:

Figure 4. 6 FTIR Analysis of pure LDPE microplastics generated in laboratory



A	2917	CH_2 Asymmetric C-H stretch
B	2852	CH_2 Symmetric C-H stretch
C	1377	CH_3 Umbrella mode
D	718	CH_2 Rock

Figure 4. 7 Reference FTIR Spectrum for LDPE microplastics (Prajapati et al., 2021)

The LDPE spectrum displays prominent peaks at:

- **2912 cm−1−1** and **2840 cm−1−1**, indicative of CH_2 stretching vibrations.
- **1460 cm−1−1**, reflecting CH_2 bending.
- **712 cm−1−1**, showing out-of-plane CH_2 wagging.

These peaks compare favorably with those reported in the literature for pure LDPE, underscoring the absence of additives or impurities that might affect the analysis. The strong correspondence between the observed peaks and those documented for LDPE confirms the suitability of the materials used for assessing microplastic removal efficacy. (Prajapati et al., 2021).

4.2.3 Polypropylene (PP)

GRAPH C:

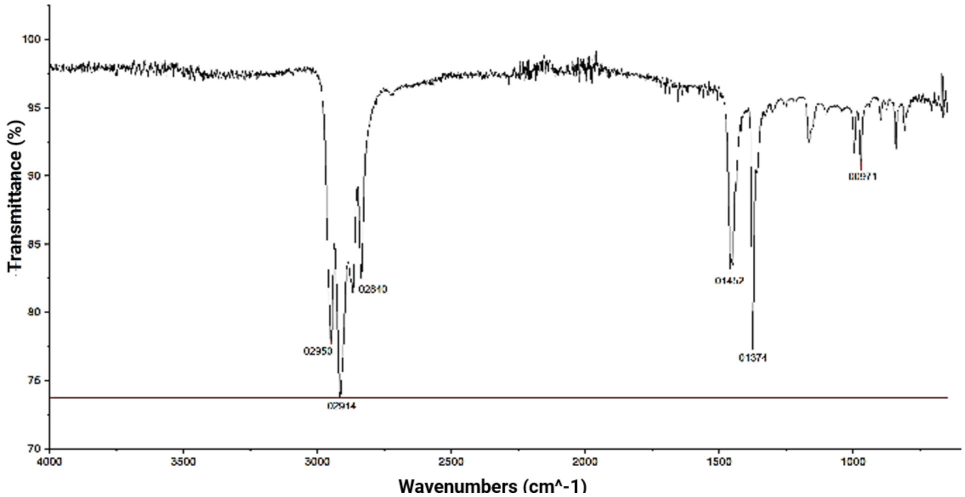
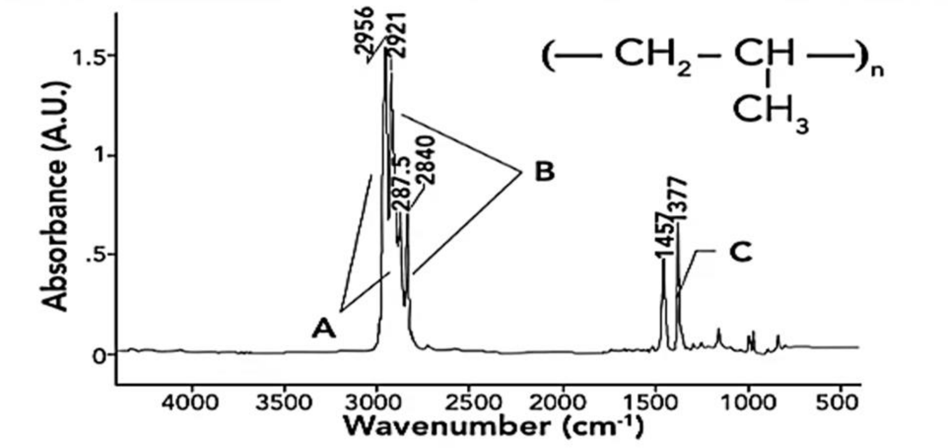


Figure 4. 8 FTIR Analysis of pure PP microplastics generated in laboratory



A	2956, 2875	CH_3 Asymmetric and symmetric stretches
B	2921, 2840	CH_2 Asymmetric and symmetric stretches
C	1377	CH_3 Umbrella mode

Figure 4. 9 Reference FTIR spectrum for PP microplastics (Prajapati et al., 2021)

For PP, the FTIR spectrum reveals:

- **2954 cm−1−1**, **2916 cm−1−1**, and **2847 cm−1−1** for CH stretching vibrations.
- **1452 cm−1−1** and **1375 cm−1−1** due to CH_3 bending.
- **998 cm−1−1** indicating the presence of tertiary carbon in PP.

These spectral features are consistent with those typically seen in pure PP samples, illustrating that our PP microplastics were also free from contaminants and processing aids that could affect experimental outcomes (Prajapati et al., 2021).

4.2.4 Discussion

The FTIR analysis provided a robust foundation for confirming the chemical integrity and purity of the microplastics used in our studies. The close match between our spectra and reference spectra confirms that the materials used were representative of typical environmental microplastics, thus ensuring the relevance and applicability of our research to real-world scenarios. This verification is crucial for the broader applicability of our findings, particularly in the development of effective strategies for microplastic remediation in water treatment processes.

4.3 Results of Scanning Electron Microscopy (SEM)

Scanning Electron Microscopy (SEM) was utilized to observe the microstructural changes in the surface of microplastics before and after the electrocoagulation process. SEM images provide crucial insights into the physical modifications at the microscopic level, which can directly influence the interaction dynamics between microplastics and coagulants during treatment.

4.3.1 SEM Analysis Before Electrocoagulation

Image 1:

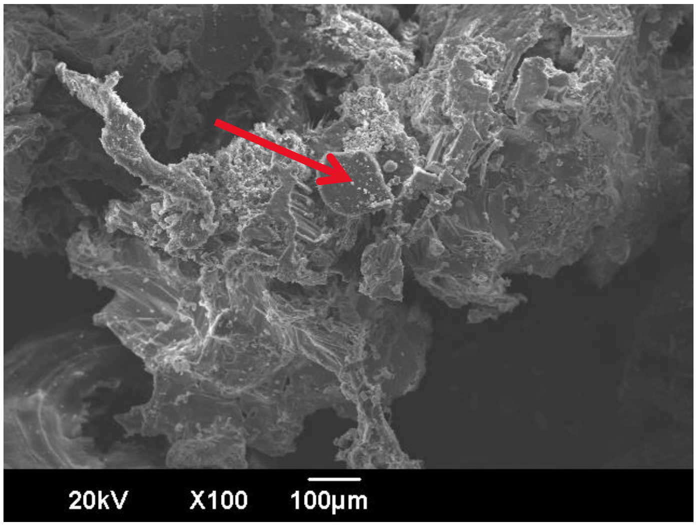


Figure 4. 10 SEM results of plastic before electrocoagulation

The initial SEM images of the microplastics exhibit a smooth and uniform surface, typical of untreated polymeric materials. These features are characteristic of microplastics in their original state, providing a baseline for comparison post-treatment. The smooth surfaces indicate minimal physical or chemical weathering prior to the experiment, which is essential for assessing the true impact of the electrocoagulation process

4.3.2 SEM Analysis After Electrocoagulation

Image 2:

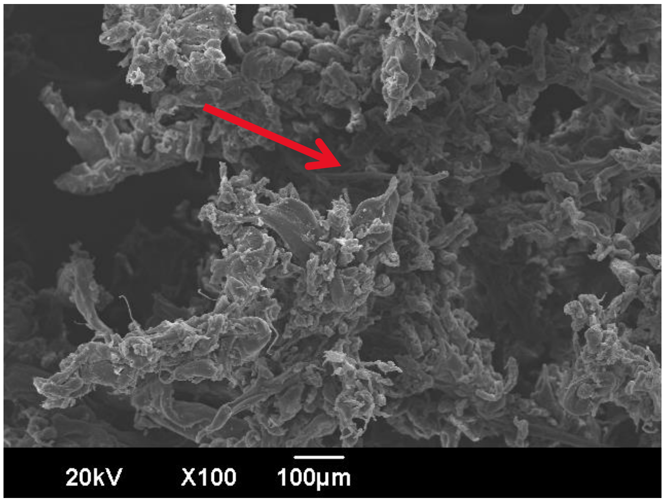


Figure 4. 11 SEM results of plastic after electrocoagulation

Post-treatment SEM images reveal significant alterations in the surface texture of the microplastics. The images show roughening of the surface, with evident etching and pitting. These changes suggest that the electrocoagulation process induces substantial physical and chemical modifications to microplastics. The formation of these features can be attributed to the destabilization of particles through the electrochemical reactions occurring at the electrode surfaces, which facilitate the aggregation and subsequent removal of microplastics.

4.3.2 Discussion

The comparative SEM analysis before and after treatment provides compelling visual evidence of the electrocoagulation process's effectiveness. The observed morphological changes are indicative of interactions between the microplastic surfaces and the coagulating agents, which are critical for enhancing the agglomeration and removal efficiency of the treatment process.

The roughened surfaces post-treatment increases the likelihood of microplastics binding with coagulants, leading to more effective aggregation. This mechanism is supported by literature suggesting that increased surface area and rougher textures enhance the adsorption of coagulants and other treatment chemicals on microplastic surfaces, thereby improving removal efficiencies.

The SEM results not only validate the operational efficacy of the electrocoagulation process but also underscore its potential for integration into existing water treatment infrastructures aimed at reducing microplastic pollution. By providing a clear microscopic view of the treatment impact, these results contribute significantly to the understanding and optimization of microplastic remediation strategies.

4.4 Analysis of Electrocoagulation Efficiency for High-Density Polyethylene (HDPE) Microplastics

4.4.1 Overview of Experimental Conditions

All experiments are conducted under the same set of conditions for all types of plastics. This segment evaluates the efficacy of the electrocoagulation process in removing High-Density Polyethylene (HDPE) from water solutions. This set utilized HDPE concentrations of 0.5 g/L. The electrocoagulation setup involved Aluminum electrodes positioned 2 cm apart, with a consistent application of 12 V for one hour. Sodium Chloride (NaCl) at a concentration of 0.5 g/L was employed as an electrolyte to enhance the conductivity of the solution (Liu et al. 2023).

4.4.2 Experimental Results

The summarized results from the electrocoagulation experiments with HDPE are presented in the following table:

No. of Experiments	**pH**	**Temperature (°C)**	**Conductivity (µS/cm)**	**Removal efficiency (%)**
Blank	6.414	20.3	1306	8
Experiment No 1	6.155	19.2	1339	86
Experiment No 2	6.026	20.9	1380	88
Experiment No 3	5.882	20.4	1329	90
Average	-	-	-	**88.0%**

Table 1. 1 Results of HDPE

4.4.3 Interpretation of results

- **Blank Experiment:**
    - The control experiment, serving as a baseline, showed a removal efficiency of 8%, indicating minimal natural degradation or settling of HDPE without electrocoagulation.
- **Experiment No 1:**
    - The first experiment showed a notable increase in removal efficiency to 86%. This suggests that the electrocoagulation parameters were nearly optimal, allowing for effective coagulation and subsequent removal of HDPE particles.
- **Experiment No 2:**
    - A further adjustment in the operational parameters resulted in a slight improvement in efficiency to 88%. The minor increase can be attributed to optimal interaction dynamics between the charged particles and the coagulant at the given pH and conductivity levels.

- **Experiment No 3:**
    - This trial achieved the highest removal efficiency at 90%, with the lowest pH value of the series. The increased efficiency at a lower pH indicates a more favorable charge environment for the coagulation and flocculation processes.

4.4.4 Discussion

The collected data underscores the capability of electrocoagulation to significantly reduce HDPE microplastic concentrations in aqueous environments. The process efficiency is highly sensitive to slight variations in pH, with lower pH conditions favoring higher removal efficiencies. Conductivity and temperature also play crucial roles, although their impacts seem less pronounced compared to pH.

A consistent temperature across the experiments suggests thermal stability in the setup, which helps in maintaining consistent reaction conditions. Variations in conductivity, influenced by changes in pH and the electrolyte's interaction, highlight the importance of ionic balance for optimal electrocoagulation performance.

The findings from these experiments demonstrate that electrocoagulation is an effective method for the removal of HDPE microplastics, with an average efficiency of 88%. This study confirms the importance of controlling electrochemical parameters, particularly pH, to achieve high removal rates. Future studies could explore the potential for integrating or optimizing other variables, such as electrode material or the spacing between electrodes, to further enhance the efficiency and applicability of the electrocoagulation method in microplastic remediation.

4.5 Analysis of Electrocoagulation Efficiency for Low-Density Polyethylene (LDPE) Microplastics

4.5.1 Experimental Results

The results from the electrocoagulation experiments are summarized in the following:

No. of Experiments	pH	Temperature (°C)	Conductivity (μS/cm)	Removal Efficiency (%)
Blank	6.1	19.7	1277	10
Experiment No 1	6.44	20	1266	94
Experiment No 2	6.81	20.1	1384	92
Experiment No 3	7.71	20.4	1304	88
Average	-	-	-	**91.3%**

Table 1. 2 Results of LDPE

4.5.2 Interpretation of Results

- **Blank Experiment**: The blank control showed a minimal removal efficiency of 10%, establishing a baseline for the effectiveness of the natural settling or minor interactions without active electrocoagulation.

- **Experiment No 1**:

    - The initial experiment resulted in a significant removal efficiency of 94%. This high rate of removal can be attributed to optimal pH adjustment and effective coagulation conditions facilitated by the electrochemical reactions at the electrode surfaces.
- **Experiment No 2**:
    - A slight increase in pH and conductivity in this trial resulted in a marginally reduced efficiency of 92%. This suggests that slight variations in pH and ionic strength of the solution can influence the electrocoagulation dynamics.
- **Experiment No 3**:
    - The highest pH value among the experiments was observed here, at 7.71, which correlated with a decrease in removal efficiency to 88%. This indicate that higher pH levels could disrupt the charge balance necessary for optimal coagulation and flocculation of LDPE particles.

4.5.3 Discussion

The data indicates that electrocoagulation is a potent method for the removal of LDPE microplastics from water. The optimal removal efficiency closely aligns with the electrocoagulation parameters of pH, conductivity, and temperature, suggesting that careful control of these factors is crucial for achieving high removal rates. The trend observed suggests a potential pH dependency, where slight alkalinity appears beneficial up to a threshold, beyond which the efficiency starts to decline.

The consistency in temperature across experiments shows that thermal factors were well-controlled and did not significantly impact the outcomes. The variances in conductivity, influenced by the varying pH levels and electrode interactions, provide insights into the conductive properties required for effective electrocoagulation.

This study demonstrates the effectiveness of electrocoagulation in removing LDPE microplastics from aqueous solutions, with an average removal efficiency of 91.3%. The findings underscore the importance of optimizing pH and conductivity within the electrocoagulation setup to maximize removal efficiencies. Further research could explore the impact of varying electrode materials and configurations to enhance the process efficiency and scalability

4.6 Analysis of Electrocoagulation Efficiency for Polypropylene (PP) Microplastics

4.6.1 Experimental Results

The table below provides the summarized results from the electrocoagulation experiments with PP:

No. of Experiments	**pH**	**Temperature (°C)**	**Conductivity (µS/cm)**	**Removal Efficiency (%)**
Blank	6.69	22.1	1229	7
Experiment No 1	6.74	19.1	990	87
Experiment No 2	7.45	21.0	1112	89
Experiment No 3	7.01	19.1	1038	87.3
Average	-	-	-	**87.8%**

Table 1. 3 Results of PP

4.6.2 Interpretation of Results

- **Blank Experiment**:
    - The control setup, without active electrocoagulation, demonstrated a minimal removal efficiency of 7%, establishing a baseline and confirming the stability of PP in the untreated solution.
- **Experiment No 1**:
    - A noticeable improvement in removal efficiency to 87% was achieved. The slight increase in pH and decrease in temperature compared to the blank enhanced the coagulation dynamics, contributing to the effective removal of PP.

- **Experiment No 2**:
    - This experiment, which featured the highest pH value at 7.45, showed an optimal removal efficiency of 89%. This suggests that the electrocoagulation process be particularly effective at slightly higher pH levels for PP removal.
- **Experiment No 3**:
    - With a pH closer to neutral at 7.01 and a return to the lower temperature of 19.1°C, the removal efficiency slightly decreased to 87.3%. This result indicates that while higher pH can enhance removal efficiency, the interplay of temperature and conductivity also influences the process outcomes.

4.6.3 Discussion

The results indicate a strong effectiveness of the electrocoagulation process in removing PP microplastics from water. The variation in pH across the experiments suggests that PP removal efficiency is particularly sensitive to changes in the electrochemical environment, with higher pH levels favoring better aggregation and flocculation of PP particles.

Temperature variations were minimal and seemed to have a less pronounced effect compared to pH. However, the conductivity changes influenced by pH adjustments and temperature show that maintaining an optimal ionic balance is crucial for maximizing electrocoagulation efficiency.

This study highlights the potential of electrocoagulation in achieving high removal efficiencies for PP microplastics, with an average efficiency of 87.8%. The findings underscore the importance of optimizing electrochemical parameters, particularly pH, to enhance the removal rates. Future research might explore the impact of different electrode materials and configurations, as well as varying types of electrolytes, to further refine and enhance the efficiency of electrocoagulation for broader water treatment applications.

4.7 Analysis of Electrocoagulation Efficiency for Mixed Microplastics (MPs) Complex

4.7.1 Experimental Results

The table below summarizes the results from the electrocoagulation experiments with mixed microplastics:

No. of Experiments	pH	Temperature (°C)	Conductivity (µS/cm)	Removal Efficiency (%)
Blank	6.28	24.7	1184	5
Experiment No 1	6.81	26.3	1287	88
Experiment No 2	6.39	24.6	1177	81.8
Experiment No 3	7.01	25.3	1059	84
Average	-	-	-	**85.7%**

Table 1. 4 Results of MP complex

4.7.2 Interpretation of Results

- **Blank Experiment**:
    - The control setup, exhibiting a minimal removal efficiency of 5%, establishes the baseline for the inherent stability of the mixed microplastics without treatment.
- **Experiment No 1**:
    - This experiment showed the highest removal efficiency at 88%, due to the optimal pH and higher temperature, which enhanced the electrocoagulation dynamics for a mixed microplastics batch.
- **Experiment No 2**:

    - With a slight reduction in pH and a similar temperature to the blank, the efficiency slightly decreased to 81.8%, indicating that pH closer to neutral can affect the efficiency negatively compared to slightly higher pH levels.

- **Experiment No 3**:
    - An increase in pH to just above neutral resulted in a moderate removal efficiency of 84%, suggesting that the electrocoagulation process be more effective at slightly higher pH levels, even with lower conductivity.

4.7.3 Discussion

The experiments indicate that electrocoagulation is a robust method for the removal of mixed microplastics, with the efficiency being sensitive to changes in pH and temperature. The mixture of different polymer types in the complex introduces variability in response to electrocoagulation, due to differences in surface properties and charge interactions among the various plastics.

4.7.4 Comparative Analysis of Removal Efficiencies

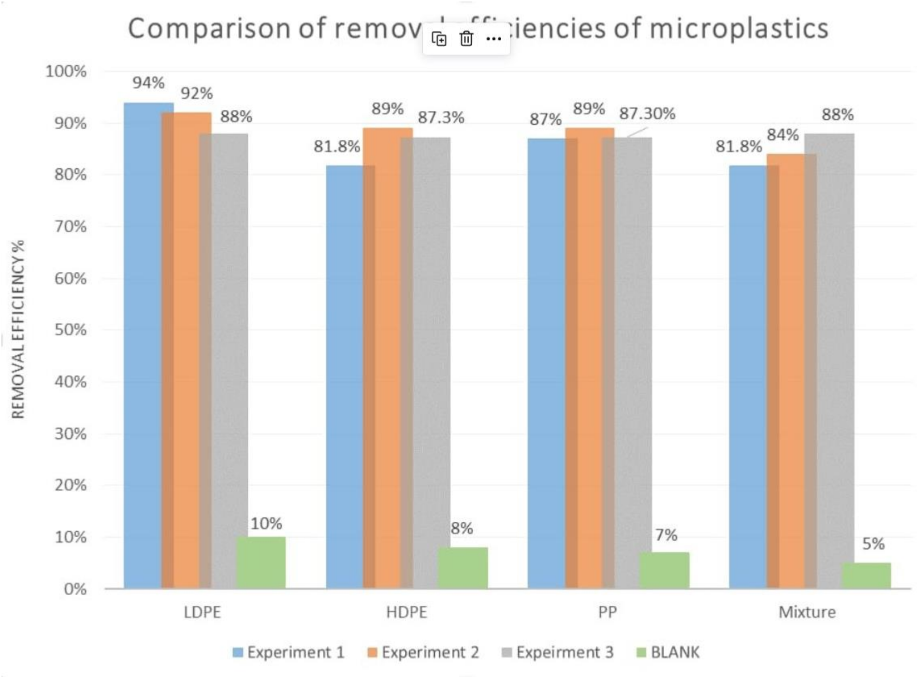


Figure 4. 12 Comparative removal efficiency of all experiments

When comparing the removal efficiencies of LDPE, HDPE, PP, and mixed microplastics, several trends and peculiarities emerge:

- **LDPE** exhibited the highest average removal efficiency, which be attributed to its lower density and potentially more amenable surface properties for electrocoagulation. LDPE's molecular structure could be more susceptible to the electrochemical reactions involved in the coagulation process, leading to higher aggregation and removal rates.

- **HDPE** and **PP** showed slightly lower efficiencies than LDPE but were still highly effective. These polymers have higher densities and different molecular structures compared to LDPE, which affect their interaction with the electrocoagulant materials and the electrochemical processes.

- **Mixed Microplastics** complex showed the lowest efficiency among the individual types. This reduced efficiency in the mixed complex can be attributed to the heterogeneity of the plastic types involved, which complicates the uniformity of the electrocoagulation process. The varying chemical and physical properties of the different microplastics in the mix lead to inconsistent coagulation and removal dynamics, as not all microplastic types respond equally to the electrocoagulation parameters.

These observations suggest that while electrocoagulation is broadly effective for microplastic removal, the specific characteristics of each plastic type, such as polymer structure, density, and surface properties, significantly influence the efficiency of the process.

4.8 Critical Analysis

This research investigates the impact of several key factors on the efficiency of the electrocoagulation process. Here, we explore the influence of inter-electrode distance and voltage, electrode material selection, solution pH, and electrolyte composition.

4.8.1 Inter-Electrode Distance and Voltage

The distance between the electrodes and the applied voltage are interrelated factors affecting electrocoagulant's efficiency. As the inter-electrode distance increases, the electrical resistance within the solution also rises. To maintain a constant current density, a higher voltage becomes necessary. However, excessively close electrode placement can destabilize the forming flocs, negatively impacting efficiency. Conversely, excessively high voltage leads to rapid electrode depletion. Our experiments identified an optimal combination of 2 cm inter-electrode distance and 12 V for efficient electro. Notably, limited literature exists on this specific optimization point, highlighting a potential area for further research (Ahmed et al., 2022).

4.8.2 Electrode material selection

Aluminum electrodes were chosen for this study due to their widespread availability, cost-effectiveness, and high efficiency compared to commonly used iron electrodes. While aluminum incurs slightly higher costs, its efficiency advantage justifies the selection. This choice aligns with findings reported in the reviewed literature, where researchers have generally recommended aluminum over iron for electrocoagulation. Ahmed et al. (2022)

4.8.3 Solution pH

The experiments were conducted at a neutral pH of 7. The pH range typically lies between 6 and 8. Observations indicated a decrease in pH during the process due to the formation of flocs, which tend to have an acidic effect on the solution. Further research could investigate methods to maintain a more stable pH level throughout the process (Ahmed et al., 2022).

4.8.4 Electrolyte composition

Sodium chloride (NaCl) at a concentration of 0.5 g per liter of distilled water was employed as the electrolyte. This selection offers a cost-effective and readily available option for the experimentation process. While other electrolytes may offer different performance characteristics, NaCl represents a good starting point for establishing a baseline efficiency (Ahmed et al., 2022).

4.9 Cost Benefit analysis

4.9.1 Costs:

- **Electrodes:** Rs. 2500 (10 pairs of aluminum electrodes)
- **Filtration:** Rs. 2470 (10 filter paper discs) - **Note:** This cost can be significantly reduced by using a reusable filter membrane or sand filtration setup.

- **Electricity:** Rs. 2.34 (0.0576 kWh * Rs. 40.26/kWh) - **Note:** This cost is negligible for the experiment scale.

Total Cost: Rs. 4970 (**Actual Experiment**) or potentially much lower with a reusable filtration setup.

Chapter 5: Future recommendations and Conclusion

5.1 Conclusion

In conclusion, our final-year design project focused on evaluating the process efficiency of electrocoagulation for removing MPs from water. Through rigorous testing and data analysis, we demonstrated that electrocoagulation is a highly efficient technique, achieving a remarkable removal effectiveness of up to 94%. Our result underscores EC technology's potential as a viable solution for addressing the growing concern of MP contamination in water bodies.

Furthermore, our collaboration with Ecobrick was instrumental in ensuring that the MPs removed through electrocoagulation process were sustainably recycled into eco-friendly bricks. This joint effort not only reduces environmental pollution but also advances the circular economy, turning waste products into valuable resources. We believe that such collaborative initiatives are key to addressing complex environmental issues. Using our prototype, we successfully removed three distinct types of MPs and their complex, demonstrating EC's potential for real-world application. This technology could be particularly beneficial in regions like Pakistan, where MP pollution is a growing concern.

Our project represents a significant stride towards resolving the pressing problem of MP pollution in aquatic bodies. Beyond presenting a viable solution, we have propelled the discourse on environmental stewardship and sustainability. Our results underscore the importance of innovative technologies and cooperative strategies in mitigating the effects of microplastic pollution, paving the way for a cleaner, more sustainable future for generations to come.

5.2 Future Recommendations

5.2.1 Using other types, size range and concentration of MPs

We used only three types of microplastics for our experimentation. The future advice involves looking into other types of MPs that are commonly found in water bodies and assessing their removal efficiency from water using electrocoagulation. The research can also be expanded by working on a different size range and different concentrations. This recommendation is an effort to improve the flexibility and sustainability of MP removal techniques and to fully evaluate the potential of electrocution for the removal of MPs.

5.2.2 Optimization of EC system

Electrocoagulation (EC) technology for the removal of MPs has the potential to advance with new electrode and reactor designs, but on-going issues such as electrode passivation and high power consumption prevent widespread use. In order to overcome these challenges, future research projects should prioritize developing sophisticated electrode and reactor architectures to increase EC efficiency significantly. Innovative designs that reduce surface coating or inactivity—such as self-cleaning or regeneration electrodes—as well as the exploration of novel materials for increased durability and reactivity, are necessary to address electrode passivation. Furthermore, it's critical to refine reactor designs to maximise mass transfer and reaction kinetics; creative topologies provide effective mixing and improved electrocoagulation kinetics.

5.2.3 Introduction renewable technologies

Integrating renewable energy sources, such as solar or wind power, into EC systems could help lower the cost of electricity and have a smaller negative impact on the environment. In addition to making electricity use more sustainable, research into the integration of renewable energy sources with EC can lay the foundation for the development of next-generation EC systems. Enhancing comprehension of working mechanisms, refining designs for the reactor and electrode, and using sustainable energy sources will all work together to raise the effectiveness and sustainability of EC for MP removal to unprecedented levels.

5.2.4 Moving to Pilot Scale

Our research at the undergraduate level, which focuses on assessing the efficiency of electrocoagulation in removing microplastics, has provided valuable insights. The experimentation and data analysis, conducted in a controlled laboratory setting, have led to findings that highlight the benefits of removing MPs from water using electrocoagulation. However, before this technique can be practically applied in water treatment plants, wastewater treatment facilities, or specific industries like the textile sector, it is crucial that further research is conducted. Our trials and results can serve as a starting point for more extensive technological optimization, but the onus is on the industries to carry this forward. The outcomes of the pilot-scale testing would be instrumental in assessing the system's functionality, challenges, and feasibility in a larger operational setting.

5.2.5 Examining microplastics in aquatic settings

Investigating possible causes of microplastic pollution, estimating the concentration and size distribution of microplastics, and assessing their frequency in aquatic habitats would be extremely helpful in optimization of MP removal methods. This can be done by conducting surveys or sampling campaigns in a range of waterways, such as rivers, lakes, and ocean. MPs can be identified and measured using techniques like spectroscopy, polymerase chain reaction (PCR), and microscopy. Additionally, investigating the influence of dissolved oxygen and dissolved organic matter on MPs removal can provide invaluable insights into real-world application scenarios, guiding more effective treatment strategies.

References

Ahmed, R., Hamid, A. K., Krebsbach, S. A., He, J., & Wang, D. (2022). Critical review of microplastics removal from the environment. In *Chemosphere* (Vol. 293). Elsevier Ltd. https://doi.org/10.1016/j.chemosphere.2022.133557

Andrady, A. L. (2011). Microplastics in the marine environment. In *Marine Pollution Bulletin* (Vol. 62, Issue 8, pp. 1596–1605). https://doi.org/10.1016/j.marpolbul.2011.05.030

Hale, R. C., Seeley, M. E., La Guardia, M. J., Mai, L., & Zeng, E. Y. (2020). A Global Perspective on Microplastics. In *Journal of Geophysical Research: Oceans* (Vol. 125, Issue 1). Blackwell Publishing Ltd. https://doi.org/10.1029/2018JC014719

Huang, S., Wang, H., Ahmad, W., Ahmad, A., Vatin, N. I., Mohamed, A. M., Deifalla, A. F., & Mehmood, I. (2022). Plastic Waste Management Strategies and Their Environmental Aspects: A Scientometric Analysis and Comprehensive Review. In *International Journal of Environmental Research and Public Health* (Vol. 19, Issue 8). MDPI. https://doi.org/10.3390/ijerph19084556

Ingelsson, M., Yasri, N., & Roberts, E. P. L. (2020). Electrode passivation, faradaic efficiency, and performance enhancement strategies in electrocoagulation—a review. In *Water Research* (Vol. 187). Elsevier Ltd. https://doi.org/10.1016/j.watres.2020.116433

Irfan, T., Khalid, S., Taneez, M., & Hashmi, M. Z. (2020). 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*, *27*(13), 15083–15092. https://doi.org/10.1007/s11356-020-07833-1

Mukheed, M., & Khan, A. (2021). *Journal of Pollution Effects & Control Plastic Pollution in Pakistan: Environmental and Health Implications Article in Journal of Pollution Effects & Control ·*. https://doi.org/10.35248/2375-4397.20.8.251

Qaiser, N., Sidra, S., Javid, A., Iqbal, A., Amjad, M., Azmat, H., Arooj, F., Farooq, K., Nimra, A., & Ali, Z. (2023). Microplastics abundance in abiotic and biotic components along aquatic food chain in two freshwater ecosystems of Pakistan. *Chemosphere*, *313*. https://doi.org/10.1016/j.chemosphere.2022.137177

Saleem, M., Bukhari, A. A., & Akram, M. N. (2011). Electrocoagulation for the treatment of Wastewater for reuse in irrigation and plantation (Report) ELECTROCOAGULATION FOR THE TREATMENT OF WASTEWATER FOR REUSE IN IRRIGATION AND PLANTATION. *Article in AUSTRALIAN JOURNAL OF BASIC AND APPLIED SCIENCES*, *7*(1). https://www.researchgate.net/publication/228481990

Senathirajah, K., Kandaiah, R., Panneerselvan, L., Sathish, C. I., & Palanisami, T. (2023). Fate and transformation of microplastics due to electrocoagulation treatment: Impacts of polymer type and shape. *Environmental Pollution*, *334*. https://doi.org/10.1016/j.envpol.2023.122159

Shen, M., Zhang, Y., Almatrafi, E., Hu, T., Zhou, C., Song, B., Zeng, Z., & Zeng, G. (2022). Efficient removal of microplastics from wastewater by an electrocoagulation process. *Chemical Engineering Journal*, *428*. https://doi.org/10.1016/j.cej.2021.131161

Yang, X., Man, Y. B., Wong, M. H., Owen, R. B., & Chow, K. L. (2022). Environmental health impacts of microplastics exposure on structural organization levels in the human body. In *Science of the Total Environment* (Vol. 825). Elsevier B.V. https://doi.org/10.1016/j.scitotenv.2022.154025

Zaied, B. K., Rashid, M., Nasrullah, M., Zularisam, A. W., Pant, D., & Singh, L. (2020). A comprehensive review on contaminants removal from pharmaceutical wastewater by electrocoagulation process. In *Science of the Total Environment* (Vol. 726). Elsevier B.V. https://doi.org/10.1016/j.scitotenv.2020.138095