Study of Separation of Linear Low Density Polyethylene (LLDPE) Microplastics from Water

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A Report Submitted in Partial Fulfillment of the Requirements for the Degree of Bachelor of Engineering (Petrochemical Engineering)
Department of Chemical Engineering, Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang
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การศึกษาการแยกพอลิเอทิลีนความหนาแน่นต่ำเชิงเส้นขนาดเล็กจากน้ำ

ปพนธีร์ แซ่อ๋อง

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Title	Separation of linear low density polyethylene (LLDPE) microplastics from water
By	Papontee Sea Ong
Field of Study	Petrochemical Engineering
Advisor	Asst. Prof. Dr. Nuttapol Lerkkasemsan

Accepted by the Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang in Partial Fulfillment of the Requirements for the Degree of Bachelor of Engineering (Petrochemical Engineering).

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Field of Study	Petrochemical Engineering
Affiliation	Engineering

Abstract

Due to the inefficient management of waste plastics, it causes degradation of the larger plastics to smaller plastics. The smaller plastics, that are known as "Microplastics", has extremely impacted on the ecology of aquatic animals and humans. Therefore, this research aims to study the efficiency of microplastics removal from water by using hydrophobic solvent and electrolysis methods. In this research, linear low density polyethylene and palm oil are used as a microplastic sample and hydrophobic solvent, respectively. The mass of microplastics is found by analytical balance. From the experiment, separation by using hydrophobic solvent method shows that 20 milliliters of palm oil can remove 86% of microplastics 100 milligrams in 1 liter of water. In part of electrolysis method, it is found that the supply of electricity at 31.5 Volts through aluminum plates in sodium chloride solution can remove 97.99% of microplastics. However, the using of hydrophobic solutions causes emulsion in water. Moreover, the separation by using electrolysis causes contamination of aluminum ion in water.

Keywords: Microplastics; Hydrophobic solvent; Electrocoagulation/ Electro-flotation

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เรื่อง การแยกพอลิเอทิลีนความหนาแน่นต่ำเชิงเส้นขนาดเล็กจากแหล่งน้ำ
โดย นาย ปพนธีร์ แซ่อ๋อง
อาจารย์ที่ปรึกษา ผศ. ดร. ณัฐพล ฤกษ์เกษมสันต์
สาขาวิชา วิศวกรรมปิโตรเคมี
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บทคัดย่อ

เนื่องจากที่ผ่านมาระบบการจัดการพลาสติกที่ใช้แล้วยังไม่มีประสิทธิภาพเพียงพอจึงทำให้พลาสติกจำนวนไม่น้อยมีการย่อยสลายกลายเป็นพลาสติกขนาดเล็กหรือไมโครพลาสติก (Microplastics) พลาสติกขนาดเล็กเหล่านี้ส่งผลกระทบต่อระบบนิเวศของสิ่งมีชีวิตเป็นจำนวนมาก โดยเฉพาะอย่างยิ่งสัตว์น้ำ ดังนั้นงานวิจัยฉบับนี้จึงมีวัตถุประสงค์เพื่อค้นหาวิธีช่วยลดปริมาณพลาสติกขนาดเล็กในแหล่งน้ำที่เหมาะสมจากการศึกษาประสิทธิภาพในการแยกพลาสติกขนาดเล็กออกจากแหล่งน้ำโดยการใช้สารละลายที่ไม่มีขั้ว (Hydrophobic solution) และการใช้ไฟฟ้า (Electrolysis) โดยพอลิเอทิลีนความหนาแน่นต่ำเชิงเส้น (Linear low density polyethylene) ถูกใช้เป็นตัวอย่างของพลาสติกขนาดเล็กและน้ำมันปาล์มถูกใช้เป็นสารละลายที่ไม่มีขั้วเพื่อทำการทดลองการแยกพลาสติกขนาดเล็กด้วยสารละลายที่ไม่มีขั้ว จากการศึกษาพบว่าการใช้สารละลายที่ไม่มีขั้ว 20 มิลลิลิตรต่อ 1 ลิตรของน้ำเสียที่มีการปนเปื้อนของพลาสติกขนาดเล็ก 100 มิลลิกรัม สามารถให้ประสิทธิภาพสูงถึงร้อยละ 86 ส่วนการแยกด้วยไฟฟ้าพบว่าการให้กระแสไฟฟ้าที่ความต่างศักย์ 31.5 โวลต์ ผ่านขั้วอะลูมิเนียมลงในสารละลายเกลือโซเดียมคลอไรด์ ความเข้มข้น 1 กรัมต่อลิตร ที่ปนเปื้อนพลาสติกขนาดเล็ก 100 มิลลิกรัม สามารถลดปริมาณพลาสติกขนาดเล็กได้มากถึงร้อยละ 97.99 อย่างไรก็ตามการใช้สารละลายที่ไม่มีขั้วและการใช้ไฟฟ้าในการแยกพลาสติกขนาดเล็กก็ยังมีข้อควรระวัง กล่าวคือ เนื่องจากการใช้สารละลายที่ไม่มีขั้วจะก่อให้เกิดอิมัลชัน (Emulsion) ระหว่างสารละลายที่ไม่มีขั้วกับน้ำได้ ส่วนการใช้ไฟฟ้าจะทำให้เกิดการปนเปื้อนของประจุอะลูมิเนียม

คำสำคัญ: พลาสติกขนาดเล็ก ตัวทำละลายที่ไม่ละลายในน้ำ การตกตะกอนและการลอยขึ้นด้วยไฟฟ้า

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Nomenclature

Nomenclature

Amp	Ampere
C	Concentration
°C	Degree Celsius
ρ	Density
g	Gram
g	Gravitational acceleration = 9.8066 m/s
LLDPE	Linear low-density polyethylene
L	Liters, Litre
m	Meters
µm	Micron, Micrometers
mg	Milligram
mm	Millimeters
min	Minutes
N/A	Not applicable, Not available, No answer
ppm	Part per million
R	Radius of particle
rpm	Rounds per minute, Round/min
v	Velocity
µ	Viscosity
V	Voltage
%w/w	Percent weight by weight, Percent weight for weight

Subscripts

Al	Aluminum plate
aq	Aqueous
f	Fluid
g	Gas
l	Liquid
p	Particles
NaCl	Sodium chloride
s	Solid

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CHAPTER I
INTRODUCTION

1.1 Background

Wastewater is an interesting problem because it impacts on humans, animals, and the environment. Wastewater will occur from the change of properties of water [1]. Water pollutions are able to be classified into a lot of types such as chemical water pollution, suspended matter, microbiological water pollution, nutrients pollution, groundwater pollution, and oxygen depleting water pollution [2].

Microplastics are one type of pollutions. They are small particles of plastics; their size is between 1 and 5000 micrometers (or 0.00004 - 0.2 inch). They were firstly reported by scientists in the 1970s [3]. However, they are being attended by the public at this time because microplastics are becoming a dangerous environmental concern [4]. In the past, the quality of water has been managed by the water pollution standards [5], but the standards are not concern about the number of microplastics. Therefore, the number of microplastics in the environment has been increasing and impacting on aquatic animals and humans. The microplastics effect on marine animals by a digestive blockage or internal damage from abrasion [6]. Moreover, it was found that microplastics might cause gastric cancer in humans [7].

Microplastics are able to be classified by source into 2 types. The first type is called “Primary microplastics”. They are small particles of plastics directly released into the environment such as microbeads, clothing, and plastic pellets or powder. In addition, another type is called “Secondary microplastics". They are small particles from the degradation of larger plastics in the environment such as fragment of fishing nets, and plastic bags [8]. It means that the microplastics are around everyone and they are occurred from the plastics consumption in daily life.

Most of microplastics were contained in wastewater of petrochemical factories. They were occurred in the production of plastics and released into the environment. Currently, the number of microplastics in wastewater of factories are still not controlled form legislation. Therefore, most of the factories ignored for microplastics removal before releasing the wastewater to the environment.

Nowadays, microplastics are analyzed by a lot of techniques such as analytical balance, spectroscope, UV-vis spectrophotometer, FTIR spectrophotometer, Raman spectrophotometer, and GC/MS-based techniques. The techniques for remove of microplastics from water are studied by scientists to reduce the plastic pollution. There

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are a lot of techniques such as degradation of microplastics, magnetic seeded filtration, and magnetic liquid. At the present, the interesting technique is the separation of microplastics by using hydrophobic solvent and electrolysis method.

In order to treat water from the factory, the aims of this project are to study the separation of microplastics from water by using hydrophobic solvent and electrolysis.

1.2 Objectives

1.2.1 To study the distribution of microplastics in water.

1.2.2 To study the efficiencies of linear low density polyethylene microplastics separation from water by using hydrophobic solvent and electrolysis.

1.3 Scopes of work

1.3.1 Polyethylene (LLDPE) with the size of 106 – 150 micrometers is used as primary microplastics.

1.3.2 The mass of microplastics are detected by analytical balance.

1.3.3 Palm oil is used as a solvent in hydrophobic solvent method.

1.3.4 Aluminum plates and sodium chloride are used as electrodes and electrolyte, respectively.

1.4 Expected outputs

Almost linear low density polyethylene microplastics in water will be removed by using hydrophobic solvent and electrolysis method.

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CHAPTER II
THEORY AND LITERATURE REVIEW

2.1 Plastics

"Plastics" is derived from the Greek "plastikos". This word means fit for molding. This is referred to the plasticity or malleability of materials [9]. Plastics are a kind of polymers. They are high molecular organic compounds. Plastic are produced by additive chemical combination of monomers or by conversion of high molecular natural materials [10]. In the present, plastics industries are growing, because they are used a growing range of applications. Plastics are used in order to produce facilities for humans in part of easier, safer, cleaner, and more enjoyable [9].

2.1.1 Classification of plastics

Plastics can be classified by the type of chemical reaction (polymerization) into 2 types consisting of:

1) Thermosetting plastics

Thermosetting plastics, resins, or polymers are a kind of material that can mold when they are melted or heated and stabilized in the shape when they are cooled in the molded. Thermosetting plastics are permanently in the shape or non-soften although they are heated again. Thermosetting plastics can be classified on the polymer chain conformation or morphology into amorphous, semi-crystalline, or liquid crystal polymers (LCPs) [11]. The common representative of thermosetting plastics includes epoxy, silicone, polyurethane, and phenolic.

2) Thermoplastic

Thermoplastics are a kind of material that can mold when they are melted or heated, stabilized in the shape when they are cooled in the molded, and soften or re-mold when they are heated again. From these characteristics, thermoplastics are called "recyclable materials". Thermoplastics, which can be further categorized into amorphous and crystalline [10], can be divided into 7 types (shown in **Table 2.1**) by the Society of the Plastics Industry (SPI code). SPI code is recommended by the British Plastics Federation and Plastics- Europe to classification [12].

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Table 2.1 Society of the Plastics Industry (SPI code), properties and application of thermoplastics [13]

SPI code	Type of thermoplastics	Properties	Application
01 PET	Polyethylene terephthalate (PET or PETE)	Clarity, strength, toughness, barrier to gas and moisture	Polyester fibers, thermoformed sheet, strapping, soft drink bottles, tote bags,
02 PE-HD	High Density Polyethylene (HDPE)	Stiffness, strength, toughness, resistance to moisture, permeability to gas	Bottles, grocery bags, milk jugs, recycling bins, agricultural pipe, base cups, car stops
03 PVC	Poly Vinyl Chloride (PVC)	Versatility, clarity, ease of blending, strength, toughness	Non-food bottles, cling films, PVC piping, children's toys.
04 PE-LD	Low Density Polyethylene (LDPE)	Ease of processing, strength, toughness, flexibility, ease of sealing, barrier to moisture	Frozen food bags, squeezable bottles, cling films, flexible container lids, wash bottles
05 PP	Polypropylene (PP)	Strength, toughness, resistance to heat, chemicals, grease and oil, versatile, barrier to moisture	Medicine bottles, yoghurt containers, ketchup bottles, margarine containers
06 PS	Polystyrene (PS)	Versatility, clarity, easily formed	Meat tray, plastic cutlery, disposable cups, compact disc cases, egg cartons, packaging foam
07 O	Others	Dependent on polymers or combimation or polymers	Baby bottles, automobile parts, safety shields/glasses.

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2.1.2 Hazards of plastics

In this time, plastics in the environment are increasing, which is dependent on the demand for plastics. However, a little of plastics are managed such as recycled or reused and the remain of plastics stay in the environment. The remaining plastics are causes of plastic pollution in the environment. Hazards or effects of plastic pollutions are a lot of effects on humans, animals, and the environment.

1) Effects of plastics on human health

a) Used plastics are becoming solid wastes. If these plastics were managed, that will become a source of pathogens.

b) Plastics are degraded that are found in human health.

2) Effects of plastics on the environment

a) Amount of plastics are added compounds for decreased degradation reaction, so these plastics use a long time for degradation and remain in the environment.

b) Plastics in the environment are degraded to small particles of plastic, that are a dangerous environmental concern.

c) Plastics are found in any animal. After that, these animals will die because plastics cannot be digested.

2.2 Microplastics

Microplastics or small plastic pollutions are small particles of plastics, that are between 1 and 5000 micrometers (or 0.00004 - 0.2 inch) of size. Microplastics are one of the most significant pollutants, that are accumulated in the environment such as floating in water and sedimentation on the ground. That is showed in **Figure 2.1**.

Figure 2.1 Plastics and microplastic pollutions in the environment [14]

Microplastics was reported the first in the 1970s by scientists [3]. In this time, microplastics are interested because microplastics are becoming a dangerous environmental concern.

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2.2.1 Sources of microplastics

Microplastics in the environment can be classified by source into 2 types include primary microplastics and secondary microplastics. The amount of microplastic in the ocean is estimated at 15 - 31% of primary microplastics and 69 - 81% of secondary microplastics, which are reported by the website of "European Parliament". Although microplastics occurred from a different source, that is dangerous to the environment [15]. Microplastics are presented in the environments, including beaches, deep-sea sediments, ocean surface waters, freshwater lakes, and tributaries, which have been investigated during the past decades, that is reported by the National Oceanic and Atmospheric Administration (NOAA) from the US Department of Commerce [4]. That showed in **Figure 2.2**.

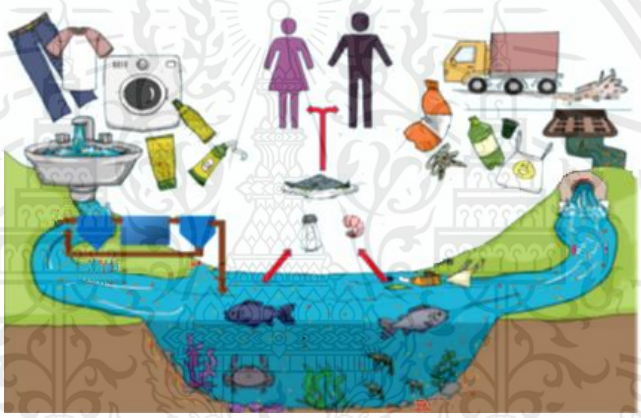

Figure 2.2 Sources of microplastics in the environment [4]

1) Primary microplastics

Primary microplastics are small particles of plastics directly released into the environment. Main sources of primary microplastics are laundering of synthetic clothes (35% of primary microplastics), abrasion of tires through driving (28%), intentionally added microplastics in personal care products such as microbeads in facial scrubs (2%) [15].

2) Secondary microplastics

Secondary microplastics are small particles from the degradation of larger plastics in the environment, that are account for 69-81% of microplastics found in the oceans. main sources of secondary microplastics include general littering and dumping of plastic waste, material discarded or lost from fishing vessels and aquaculture facilities and Material lost or discarded from merchant ships [15].

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2.2.2 Type of microplastics

1) Shapes of microplastic

In the environment, microplastics are occurred from different of sources, that are different of shapes such as fragments, line, and flake (shows in **Figure 2.3**).

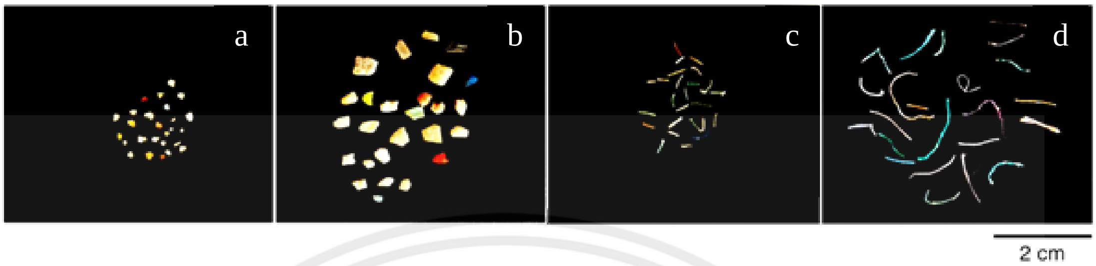

Figure 2.3 Microplastic sizes and types: (a) Fragments 0.5–1.5 mm, (b) Fragments 1.5–5.0 mm, (c) Lines 0.5–1.5 mm and (d) Lines 1.5–5.0 m [16]

2) Type of polymer

Microplastics in the environment are classified in various types of polymer because there occurred different sources (shows in **Table 2.2**).

Table 2.2 Selection of reported polymer compositions in a variety of media [17]

Matrix	Size (mm)	Polymer composition	Reference
Sediment/ shoreline	<1	PES (56%), AC (23%), PP (7%), PE (6%), PA (3%)	Browne et al. (2011)
Sediment/ beach	1–5 mm (pellet)	PE (54, 87, 90, 78%), PP (32, 13, 10, 22%)	Karapanagioti et al. (2011)
Water/ sewage effluent	<1	PES (67%), AC (17%), PA (16%)	Browne et al. (2011)
Fish	0.13–14.3	PA (35.6%), PES (5.1%), PS (0.9%), LDPE (0.3%), AC (0.3%), rayon (57.8%)	Lusher et al. (2013)
Bird	-	PE (50.5%), PP (22.8%), PC and ABS (3.4%), PS (0.6%), not identified (22.8%)	Yamashita et al. (2011)

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2.2.3 Identification of microplastics

Microplastics can be identified by a lot of techniques. In most studies, first identifications of microplastics are visual, before identification of the polymer type is undertaken such as larger particles can be identified with the naked eye, whereas small microplastics are identified using binocular microscopes or scanning electron microscopy (SEM). Moreover, microplastics can be classified by density, that is an easy method. However, visual identification is often insufficient resulting in false-positive results. For this reason, spectroscopic or spectrometric methods are needed to ensure the unambiguous identification of particles made from synthetic polymers [4].

Spectroscopic identification methods are used for identified microplastics include Fourier transform infrared (FTIR) spectroscopy and Raman spectroscopy. These methods are based on the energy absorption of each characteristic function groups of polymer particles. limit of particle size is measured between 10 and 20 μm for FTIR measurements, while Raman instruments can measure particle with sizes that are one to two orders of magnitude smaller. However, identification of microplastics with FTIR spectroscopy and Raman spectroscopy is susceptible to environmentally driven changes of the polymer surface or the additive application during polymer processing [4].

For this reason, pyrolysis-gas chromatography/mass spectrometry (Pyr-GC/MS) are needed to ensure the unambiguous identification of microplastics and additives. Pyrolysis-gas chromatography/mass spectrometry (Pyr-GC/MS) is used for the determination of the polymer type and polymer additives by combustion of the sample and the detection of the thermal degradation products of the polymers [4].

SEM and energy-dispersive X-ray spectroscopy (SEM-EDS) can be used to provides elemental analysis of the measured objects and produces high-resolution images of the particles. Therefore, this method is used to distinguish between microplastics and particles that are composed of inorganic elements [4].

2.2.4 Hazards of microplastics

Microplastics can be occurred from spontaneous sources and industry in the environment, that are causes of microplastic pollution in the environment. Hazards or effects of microplastic pollutions are a lot of effects on humans, animals, and the environment. A lot of researchers reported the detection of microplastics in the food chain, thus human beings are exposed to its potential harms [4].

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Research of Davidson and coworkers reported the presence of microplastics in Manila clams in British Columbia. The impact of microplastics on aquatic organisms can occur from many pathways. The cause of the physical blockage and internal abrasions can occur from the ingestion of microplastics. Furthermore, the leakage of additives and contaminants in microplastic impact on the organisms [4].

Nowadays, there is not research that reported about the direct impact of microplastics on human. These topics will be studying by the researchers because microplastics are detected in the stool of humans and maybe cause gastric cancer [4].

2.3 Managements of microplastics from water

Microplastics in water are concern problems. The researchers are developing techniques to managements of microplastics from water. Nowadays, there are a lot of techniques such as degradation of microplastics, magnetic seeded filtration, and magnetic liquid or extraction.

2.3.1 Degradation

Degradation of microplastics is one technique to managed microplastics in the environment. In the environment, the degradation of plastics is able to occur spontaneously, but it takes a long time. Thus, this technique is developed from the basic of degradation of plastics in the environment. Degradation of synthetic polymers can generally be classified as biotic or abiotic, following different mechanisms, depending on a variety of physical, chemical, or biological factors. The most important processes for the degradation of synthetic polymers can be divided into (shows in **Figure 2.4**) [18].

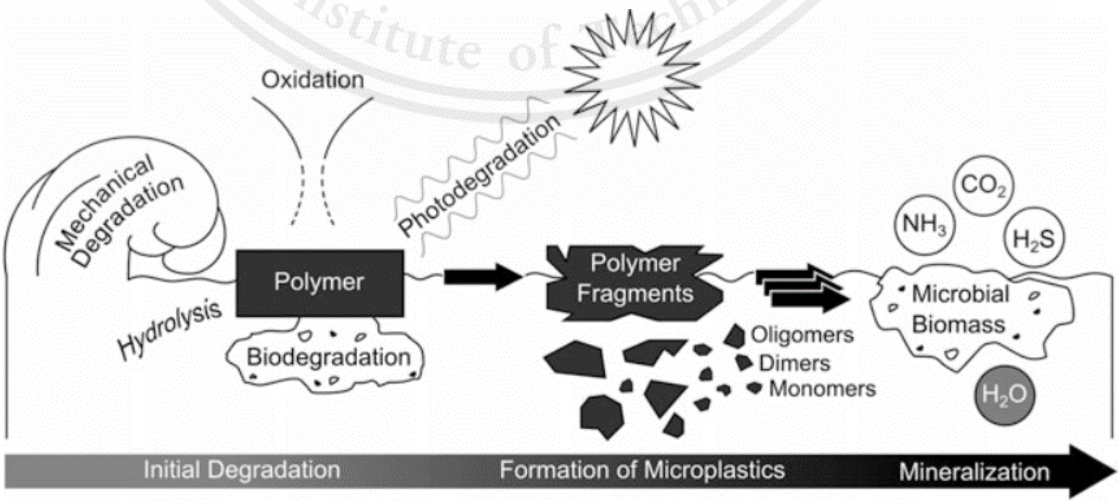

Figure 2.4 Degradation of microplastics [18]

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1) Physical degradations involves changes to materials resulting from ambient conditions like abrasive forces, sunlight, heat/cooling, freezing/thawing, wetting/drying, humidity, exposure to chemicals or general wear and tear [18].

2) Photodegradation or Photo-oxidation involves changes to materials resulting from light-induced homolytic fission of chemical bonds. This technique is usually using a UV light on the degradation of microplastic. This process is able to occur spontaneously although, it is not catalysts [18].

3) Chemical degradation involves changes to material resulting from oxidation or hydrolysis reaction [18].

4) Biodegradation involves changes to material resulting from degradation by the organisms. The organisms are able to degradation of microplastics divide as bacteria, fungi, and algae. This technique is coupled to three essential criteria. First, the environmental parameters such as temperature, pH, moisture, and salinity must provide conditions. Second, microorganisms must be degraded the microplastics with enzymes. Furthermore, The morphology of polymer particles must render the attachment of microorganisms [18]

2.3.2 Extraction of microplastics from water

The extraction of microplastic from water is interested technique at this time. Hydrophobic solvents are used to extract microplastics from water. Example of used hydrophobic solvents (shown in **Table 2.3**) including palm oil, soybean oil, benzene (C_6H_6), diethyl ether ($CH_3CH_2OCH_2CH_3$), hexane ($CH_3(CH_2)_4CH_3$), methylene chloride (CH_2Cl_2). Results of researches shown microplastics are able to extract by hydrophobic solvents [19].

Table 2.3 Solubility of immiscible non-polar organic solvents in water

Solvent	Dielectric constant	Solubility in water (%w/w)
Pentane	1.84	0.004
Hexane	1.90	0.001
Cyclohexane	2.01	0.0055
Carbon tetrachloride	2.2	0.08
Benzene	2.28	0.18
Toluene	2.38	0.051
Water	80.10	100

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2.3.3 Filtration

Filtration of microplastics is an easy and handy technique to remove microplastics from water. However, this technique causes a lot of waste. The filtration of microplastics is developed by scientists such as magnetic seeded filtration. Magnetic seeded filtration is increasing efficacy and reduce waste. The equipment of magnetic seeded filtration is shown in **Figure 2.5** [20].

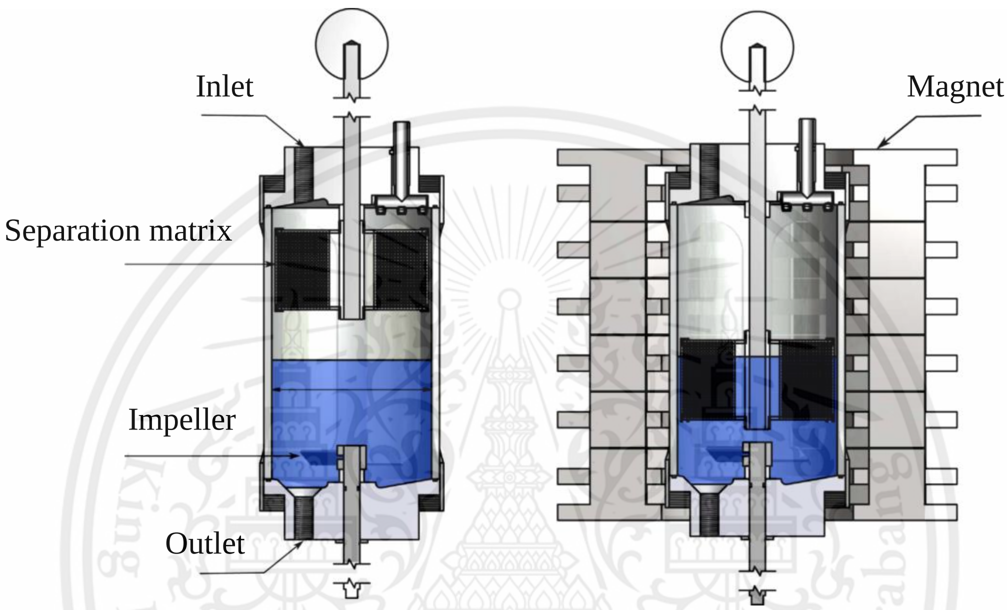

Figure 2.5 Agglomeration cell: (a) agglomeration, (b) separation [20]

2.4 Literature review

The separation of microplastics from water is developed by many researchers. In the present, interesting research is the technique of the separation of microplastics from the water by using hydrophobic solvent and electrolysis.

A. Oladejo [19] studied the technique of removal of microplastic from water with an organic medium. In his work, plastics were grinded and sieved, which were used as a sample of microplastics. He studied the effect on the stir of solution. The analytical balance was used to weight the mass of microplastics. Results showed that microplastics could be successfully extracted from water with oil. Moreover, microplastics could be well removed from water when the solution is vigorously mixing.

F. Ferreira [21] studied an investigation into the removal of microplastics from water using ferrofluids. In his work, oil was used to extract microplastics from water.

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the mixed solution was treated with non-toxic iron oxide or magnetite powder, which was removed using strong magnets. The concentration of microplastics was detected with visible light spectrometer and microscope. The result showed that 87.6% ± 1.1% of microplastics were removed from water. This method was most effective on fibers obtained from a washing machine and least effective on polypropylene plastics.

W. Perren et al.[22] studied removal of microbeads from wastewater using electrocoagulation. In their work, the effects of the wastewater characteristics include initial pH, NaCl concentration, and current density on removal efficiency were studied. The control variables were including polyethylene microbeads concentration and 1 L stirred-tank batch reactor. The result showed that microbeads removal efficiencies more than 90% were observed in all experiments. The optimum condition for removal microbeads was found at a pH of 7.5, 0 – 2 g/L of NaCl concentration, and 11 Amp/m^2 of current density.

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CHAPTER III
RESEARCH METHODOLOGY

3.1 Equipment and materials

3.1.1 Materials

1) Polyethylene (Pellets)

2) Deionized water

3) Hydrophobic solvent (Palm oil)

4) Electrolyte (Sodium chloride: NaCl)

5) Electrodes (4 Aluminum sheets: 150 mm × 30 mm × 1 mm)

6) Polylactic acid (PLA)

7) Electrode holder

In the microplastics separation by using electrolysis, that must use electrodes holder to hold the electrodes. The properties of electrodes holder include electrical insulation/ low conductivity, high tensile strength, and inexpensive. In this experiment, the electrodes holder was designed and drawn with the Tinkercad website. After that, the electrodes holder model from the Tinkercad website was molded with the 3D Printer. Polylactic acid (PLA) was used material to make the electrodes holder. That showed in **Figure 3.1**.

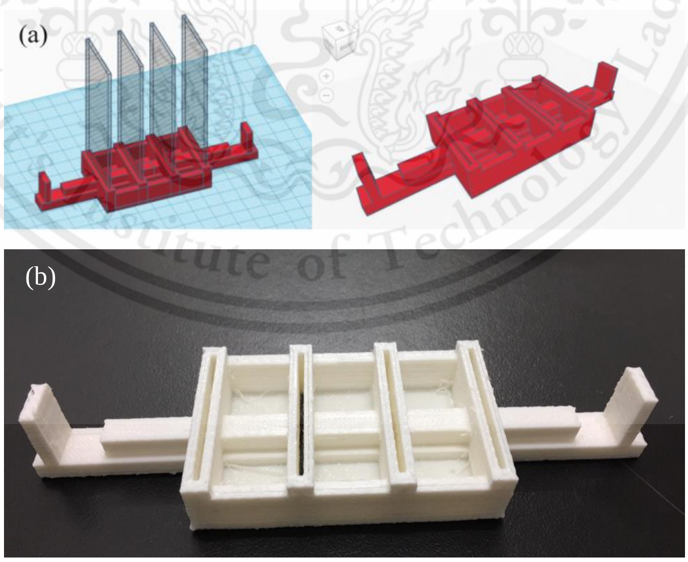

Figure 3.1 Design of electrodes holder: (a) model drawn with Tinkercad website software; (b) electrodes holder printed with 3D printer

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3.1.2 Equipment and software

1) Filter papers (Whatman No.1)
2) Erlenmeyer flasks and funnels
3) Beaker (Pyrex® 1,000 mL)
4) Grinder machine
5) Sieving machine (Mesh size 106 – 150 µm)
6) Magnetic stirrer (StableTemp)
7) Analytical balance (BAS 31 Plus)
8) Universal oven (Memmert)
9) Regulated power supply (WANPTEK®)
10) 3D printer
11) Tinkercad website
12) CURA 15.04.3 software
13) STATISTICA 10 software
14) Microsoft EXCEL software

3.2 Procedures of experiment

This experiment can be divided into 3 parts including preparation of microplastics, separation of microplastics from water by using hydrophobic solvents and electrolysis (electrocoagulation/ electro-flotation method), and data analysis. That shown in **Figure 3.2**.

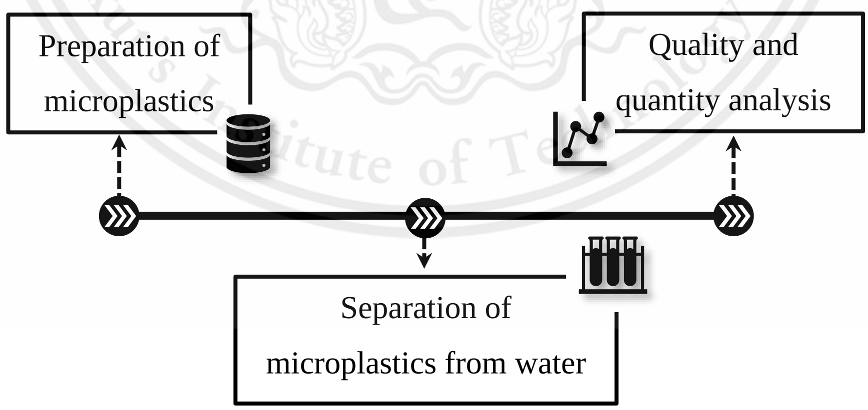

Figure 3.2 Procedures of the experiment

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3.2.1 Preparation of microplastics

Polyethylene powder from SCG ICO Polymers Co., Ltd. is used as samples. The size of samples is necessary to be less than 5 millimeters.

(a) Measure size of polyethylene powder by sieving machine. Mesh with size of 106 -150 micrometers is used in sieving machine.

(b) Collect microplastics that are 106 -150 micrometers of size in bottles.

3.2.2 Separation of microplastics from water by using hydrophobic solvents

This method can be divided into 2 parts including separation of microplastics from water, and analysis of quality and quantity.

1) Separation of microplastics from water

In this section, Hydrophobic solvent is independent variable. They are used for separation of microplastics from water. The controlled variables are volume of deionized water and mass of microplastics. Step of separation of microplastics is shown in **Figure 3.3**.

(a) Measure the volume of deionized water around 1 L and add it into the beaker.

(b) Weight a mass of microplastics around 0.1 grams and add it into the beaker.

(c) Mix the mixed (microplastics and deionized water) with magnetic stirrer at 350 rpm, 30 minutes.

(d) Prepare various volume of palm oil (0, 5, 10, 15, and 20 mL) and add it into the beaker. Then, mix the solution at 350 rpm, 2 minutes.

(e) Decrease the speed of stirrer to 60 rpm and start count time. After that, sampling 50 mL of mixture at 2, 7, 12, 22, and 32 minutes and keep that in beakers.

(f) Repeat steps (a) - (e) but change the speed of stirrer at step (c) and (d) from 350 rpm to 700 rpm.

2) Analysis of quality and quantity

(a) Filter microplastics from samples by using filter paper.

(b) Dry filter paper in an oven at 105 °C for 5 hours.

(c) Weight mass of microplastics on filter paper.

(d) Record and analyze the data from the experiment with Microsoft EXCEL and STATISTICA 10 software.

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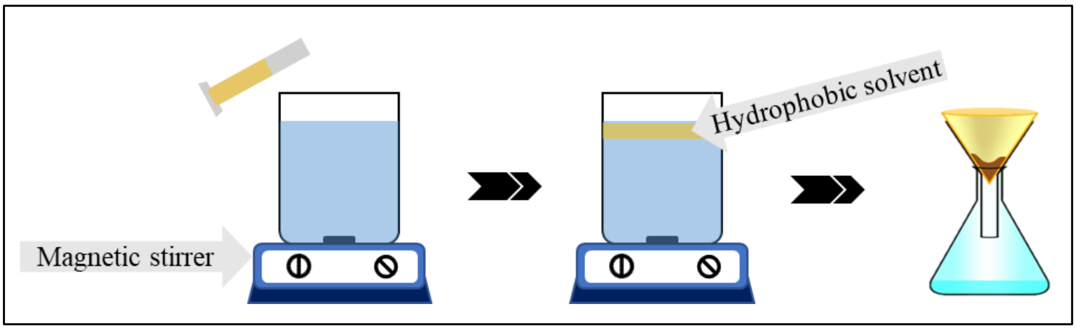

Figure 3.3 Steps for separate the microplastics from water by using hydrophobic solvent

3.2.3 Separation of microplastics from water by using electrolysis method (electrocoagulation/electro-flotation method)

This method can be divided into 2 parts including separation of microplastics from water, and analysis of quality and quantity.

1) Separation of microplastics from water

In this section, Concentration of sodium chloride and current are independent variable. They are used for separation of microplastics from water. The controlled variables are volume of deionized water, mass of microplastics and number of electrodes. Step of separation of microplastics is shown in **Figure 3.4**.

(a) Measure the volume of deionized water around 1 L and add it into the beaker.

(b) Weight a mass of microplastics around 0.1 grams and add it into the beaker.

(c) Mix the mixed (microplastics and deionized water) with magnetic stirrer at 350 rpm, 30 minutes.

(d) Prepare various weight of sodium chloride (1, 2, and 3 g) and add it into the beaker. Then, mix the mixture (microplastics, deionized water, and sodium chloride) at 350 rpm for 2 minutes.

(e) Decrease the speed of stirrer to 60 rpm, load the electrodes, and apply current. After that, start count time and sampling 50 mL of mixture at 2, 7, 12, 22, and 32 minutes and keep that in beakers.

(f) Repeat steps (a) - (e) but replace the speed of stirrer at step (c) and (d) from 350 rpm to 700 rpm.

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2) Analysis of quality and quantity

(a) Filter microplastics from samples by using filter paper.

(b) Dry filter paper in an oven at 105 °C for 5 hours.

(c) Weight mass of microplastics on filter paper.

(d) Record and analyze the data from the experiment with Microsoft EXCEL and STATISTICA 10 software.

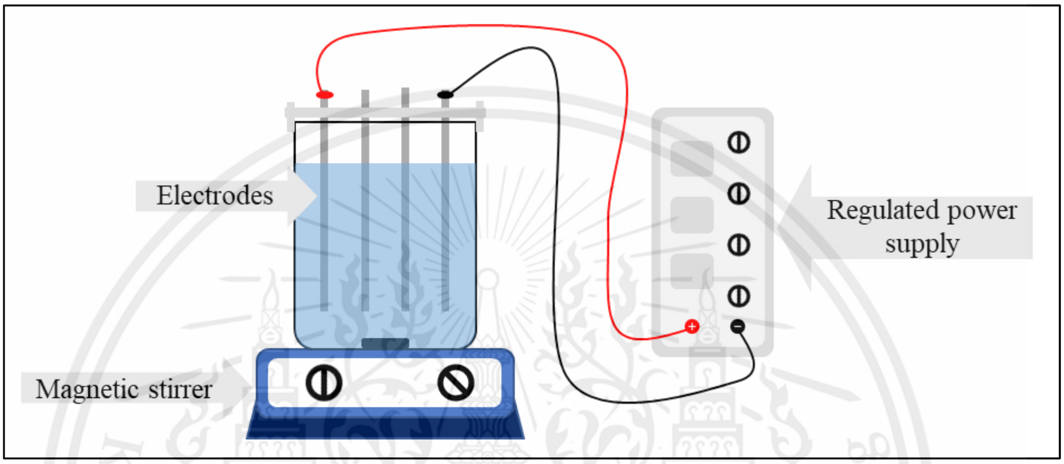

Figure 3.4 Schematic of electrolysis setting for separate microplastics from water

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CHAPTER IV
RESULT AND DISCUSSION

This research studied the distribution of microplastics in water and separation efficiencies of microplastics from water. Analytical balance (BAS 31 Plus) was used to analyze equipment to explain the distribution and removal efficiencies of microplastics at different times and conditions. Separation techniques to remove the microplastics from water are divided into 2 techniques. The first technique is extraction of microplastics by using hydrophobic solvent, which is palm oil. Another technique is electrolysis method, which is electrocoagulation/ electro-flotation.

4.1 Effect of stirring rate on removal of microplastics

Generally, the distribution of solid particles in liquid is based on theory of sedimentation and flotation. The Stokes' law, that shows in **(4-1)**, is used to explain the principle of sedimentation or flotation of sphere particle with small Reynolds numbers in a viscous fluid.

$$v = \frac{2}{9}\frac{(\rho_p - \rho_f)}{\mu} g R^2 \qquad \textbf{(4-1)}$$

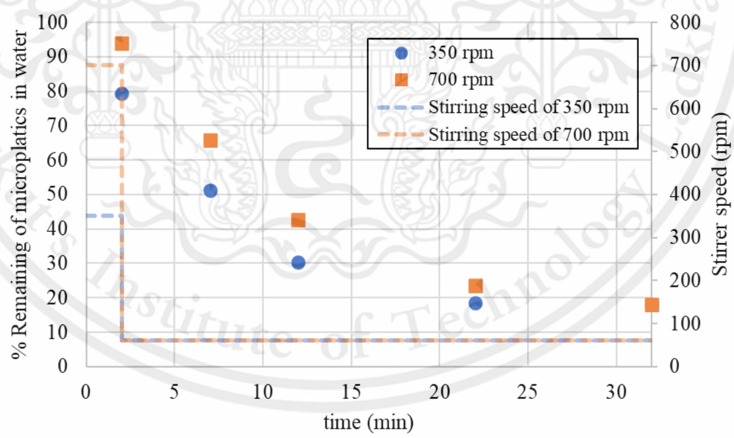

Figure 4.1 Distribution of microplastics in water against time. All other reactor conditions: initial microplastics concentration, 0.1 g/L; and stirring speed, 60 rpm

This part studied the distribution of microplastics in water after it was mixed at different stirring speeds. Microplastics and water were mixed at 350 and 700 rpm for 2 minutes. After that, the stirring speed of solution was decreased to be 60 rpm. 50 mL of the solution was sampled at the time of 2, 7, 12, 22, and 32 minutes. From the study, the result was shown in **Figure 4.1**. This data showed the effect of stirring speed on the

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remaining microplastics in water. The remaining microplastics in water decreased according to the theory of flotation. Due to the lower density of polyethylene than water, the polyethylene tended to float when the time passed. Moreover, when mixing speed is higher, the remaining microplastics will be higher as the microplastics can be circulated and distributed in water better than at lower mixing speed.

4.2 Separation of microplastics from water by using hydrophobic solvent

The palm oil was used as a hydrophobic solvent sample for separation of microplastics from water. The advantages of palm oil for this separation included no toxic, low density, low solubility in water, and inexpensive. The density of palm oil is lower than water and the solubility of palm oil in water is low, which is the benefit to the treatment of wastewater after the microplastics were removed from the water. In addition, the difference of density between palm oil and polyethylene powder is lower than water and polyethylene powder that is the usefulness of microplastics separation from water.

However, palm oil was used to separate microplastics that causes emulsion between palm oil and water. The emulsion, that will occur when mixing solution were high stirring speeds or flow rate, was a disadvantage for water treatment because that took a long time to treatment.

In this part of the experiment, microplastics and water were mixed at 700 rpm of stirring speed for 30 min. Then palm oil was added and the stirring speed was decreased to 300 and 700 rpm of 2 min. After that, the solution is decreased to 60 rpm. 50 mL of the solution was sampled at the time of 2, 7, 12, 22, and 32 minutes. The result of microplastics removal efficiency versus time at different volumes of palm oil was shown in **Figure 4.2**.

Figure 4.2 (a) and **(b)** were showed the result of stirring speed at 350 rpm for mixing 1 liter of water that contaminate 100 milligrams of microplastics with palm oil. The result showed volumes of palm oil were slightly increased the initial removal efficiencies of microplastics. **Figure 4.2 (c)** and **(d)** were showed the result of mixing speed at 700 rpm to mix the solution and palm oil. The result showed volumes of palm oil were slightly increased the initial removal efficiencies of microplastics, but it was a highly significant effect when compared with 0 mL of palm oil. The microplastics removal efficiencies of both speeds were rapid increase with time and reaches a plateau after 20 minutes. Moreover, volumes of palm oil were a small significant effect on the final microplastics removal efficiencies.

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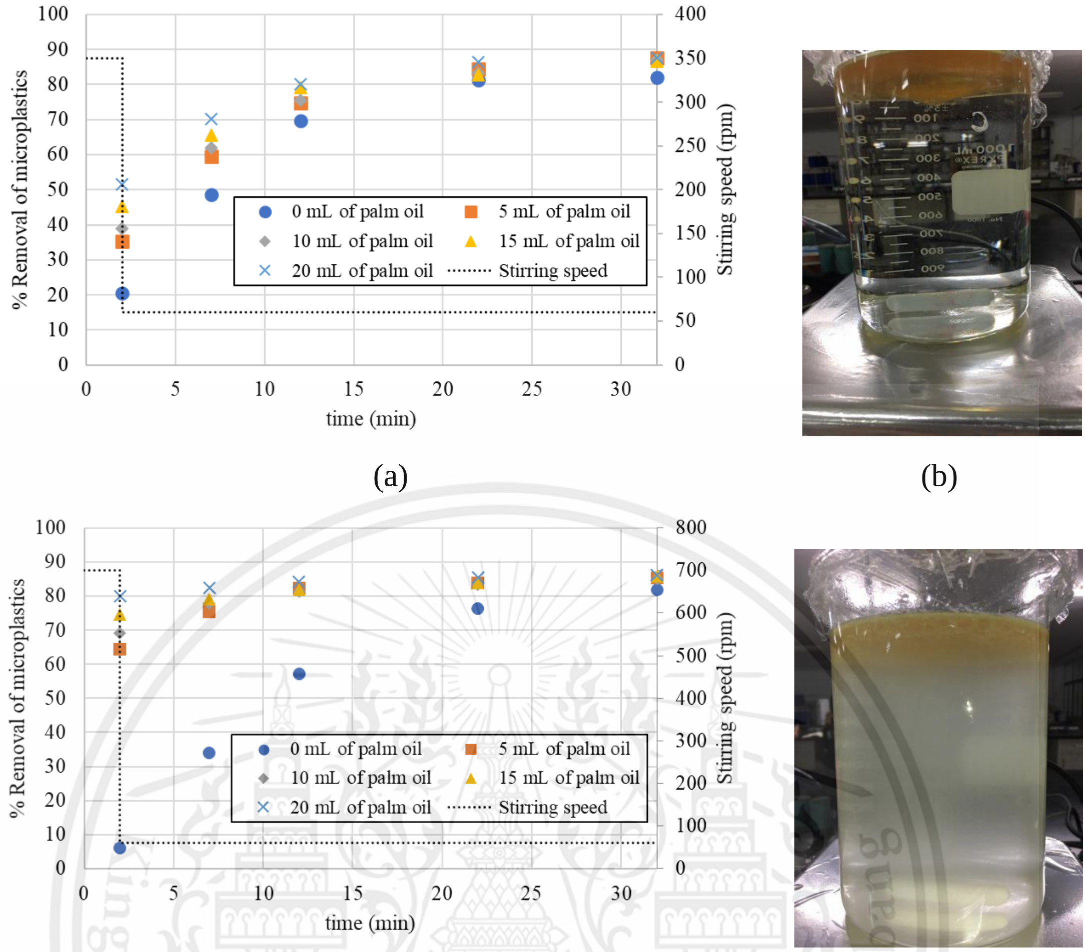

(a) (b)

(c) (d)

Figure 4.2 %Removal of microplastics versus time at different volume of hydrophobic solvent (Palm oil): (a), (b) 350 rpm of mixing speed and (c), (d) 700 rpm of mixing speed

From the experiment in this part, palm oil can be used to separate the microplastics from water. The result of both mixing speeds shows when the volume of palm oil was increased, the initial efficiency of microplastics separation will be increased because the concentration of palm oil increased. Moreover, the initial efficiency will be increased when the mixing speed was increased. As the droplet of palm oil will be smaller when increase in the stirrer speed, so the contact area of palm oil was increased. However, at high mixing speed affect the form of emulsion like **Figure 4.2 (b)** and **(d)**.

4.3 Separation of microplastics from water by using electrolysis

In this experiment, the separation of microplastics from water by using the electrolysis process (Electrocoagulation/ Electro-flotation) was liberating metal ions

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from electrodes into water. Aluminum plates and sodium chloride were used as electrodes and electrolyte, respectively. Bipolar electrodes connection was connected 4 electrodes. The effect of sodium chloride concentration and removal efficiencies were studied in this part. The main reactions showed in the equations **(4-2) - (4-6)**. The anodic and cathodic reactions are given in equations **(4-2) - (4-3)** and **(4-4) - (4-5)**, respectively.

$$Al_{(s)} \rightarrow Al^{3+}_{(aq)} + 3e^{-} \qquad \textbf{(4-2)}$$

$$2H_2O_{(l)} \rightarrow 4H^{+}_{(aq)} + O_{2(g)} + 4e^{-} \qquad \textbf{(4-3)}$$

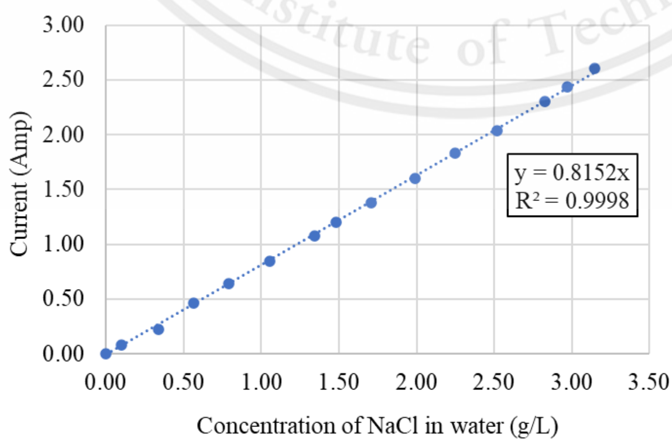
$$Al^{3+}_{(aq)} + 3e^{-} \rightarrow Al_{(s)} \qquad \textbf{(4-4)}$$

$$2H_2O_{(l)} + 2e^{-} \rightarrow H_{2(g)} + 2OH^{-}_{(aq)} \qquad \textbf{(4-5)}$$

$$Al^{3+}_{(aq)} + 3OH^{-}_{(aq)} \rightarrow Al(OH)_{3(s)} \qquad \textbf{(4-6)}$$

4.3.1 Effect of NaCl concentrations

The conductivity of electrolyte solution presented the ability of the medium to carry electricity. When the solution consisting of many ions, it will easily transfer the electricity. **Figure 4.3** showed the result of electric current measurement at 31.5 V of solution at various sodium chloride concentration. There was a linear relationship between electric current values and sodium chloride concentration. The linear equation was y = 0.8152x. Therefore, the electric current of the solution will be increased as the concentration of sodium chloride increased because the conductivity was increased. Moreover, increase in electrical current caused increasing in the liberation of aluminum hydroxide from the electrodes. This phenomenon affected the turbidity of water.



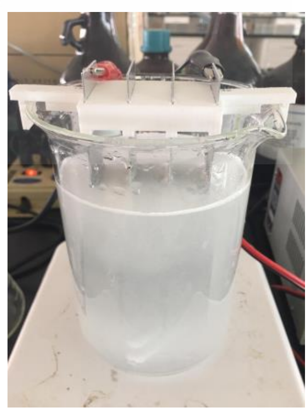


Figure 4.3 The plot of the current (Amp) in aqueous various NaCl concentration (g/L). All other reactor conditions: Voltage, 31.5 V; and stirring speed, 60 rpm

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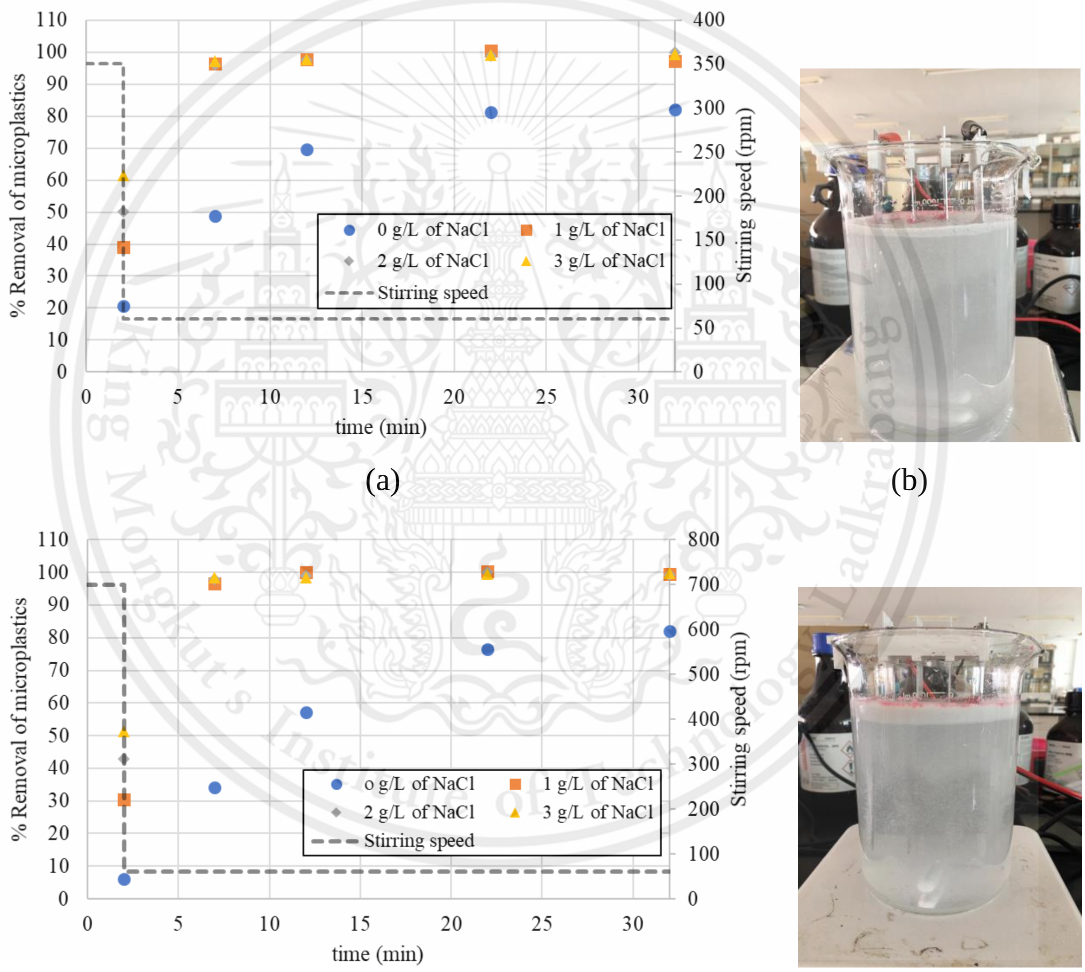
4.3.2 Effect of electrolysis on microplastics removal

In this part of the experiment, microplastics and water were mixed at 700 rpm of stirring speed for 30 min. Then sodium chloride was added and the stirring speed was decreased to 300 and 700 rpm of 2 min. After that, the solution is decreased to 60 rpm and the electrodes will be soaked into the solution. Then, the power supply was turned on and start count time. 50 mL of the solution was sampled at the time of 2, 7, 12, 22, and 32 minutes. The result of microplastics removal efficiency against time at different concentrations of sodium chloride (NaCl) was shown in **Figure 4.4**.



(c) (d)

Figure 4.4 Microplastics removal efficiency against time at different concentration of sodium chloride (NaCl): (a), (b) 350 rpm of mixing speed and (c), (d) 700 rpm of mixing speed

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Figure 4.4 (a) and **(b)** were showed the result of stirring speed at 350 rpm for mixing 1 liter of water that contaminate 100 milligrams of microplastics with sodium chloride. The result showed sodium chloride concentrations were slightly increased the initial removal efficiencies of microplastics. **Figure 4.4 (c)** and **(d)** were showed the result of mixing speed at 700 rpm to mix solution and sodium chloride. The result showed sodium chloride concentrations were slightly increased the initial removal efficiencies of microplastics. However, both speeds were highly significant efficiencies when compared with 0 grams of sodium chloride. For all the concentrations investigated, the microplastics removal efficiency increases rapidly with time and reaches a steady - state after 10 minutes of electrolysis operation.

From the experiment in this part, electrolysis method can be used to separate the microplastics from water. The maximum removal efficiency was found to be 90 − 100% after 10 minutes of electrolysis operation. The result of both mixing speeds shows when the concentration of sodium chloride was increased, the initial efficiency of microplastics separation will be increased because of high concentration of aluminum hydroxide. However, the increase in NaCl was a small significant effect on the separation time. Moreover, the initial efficiency will be decreased when the mixing speed was increased as a result of the distribution of microplastics and aluminum hydroxide like **Figure 4.4 (b)** and **(d)**.

4.4 Comparison of both techniques

From this study, electrolysis and extraction by using hydrophobic solvent were able to use for removing the microplastics from water. The efficiencies of both techniques were excess than 85%. However, the separation of microplastics from the water by using hydrophobic solvent and electrolysis have some disadvantage. The disadvantage of extraction by using hydrophobic solvent causes emulsion between hydrophobic and water. The disadvantage of electrolysis is contamination of metal ion.

4.4.1 Operating cost

The operating cost of the hydrophobic solvent method is the cost of using solvent. The maximum removal efficiency of 86% was found when using 20 milliliters of palm oil in 1 liter of wastewater that contained 100 milligrams of microplastics. For this condition, spend the cost of 0.6 bath (shown in **(4-7)**).

$$\text{cost} = \left(30\,\frac{฿}{L_{oil}}\right) \times \left(20\,\frac{mL_{oil}}{L_{water}}\right) \times \left(\frac{1}{1000}\,\frac{L}{mL}\right) = 0.600\,\frac{฿}{L_{water}} \qquad \textbf{(4-7)}$$

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The operating cost of the electrolysis method is the cost of electrode, electrical, and electrolyte. The maximum separation efficiency of 97.99% was found when using 1 gram of sodium chloride in 1 liter of wastewater, which contained 100 milligrams of microplastics. For this condition, spend the cost of 0.22 bath (shown in **(4-8)**).

$$\text{cost} = \left\{ \begin{array}{c} \left(0.63\ \frac{฿}{g_{Al}}\right)\times\left(0.17\ g_{Al}\right) + \\ (31.5\ V)\times(0.9\ A)\times\left(\frac{10}{60}\ h\right)\times\left(\frac{1}{3600}\ \frac{unit}{J}\right)\times\left(4\ \frac{฿}{unit}\right) + \\ \left(110\ \frac{฿}{kg_{NaCl}}\right)\times\left(1\ g_{NaCl}\right)\times\left(\frac{1}{1000}\ \frac{kg}{g}\right) \end{array} \right\} = 0.222\ \frac{฿}{L_{water}} \quad \textbf{(4-8)}$$

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CHAPTER V
CONCLUSION

5.1 Conclusion

In the present, the microplastics are becoming a dangerous environmental concern. The microplastics have been extremely impacting on aquatic animals and humans. Therefore, this research aims to study the efficiency of microplastics removal from water by using hydrophobic solvent and electrolysis methods.

In this study, linear low density polyethylene, palm oil, sodium chloride, and aluminum sheets were used as the plastic sample, hydrophobic solution sample, electrolyte, and electrodes, respectively. The concentration of microplastics in water was calculated from the remaining mass of microplastics on filter papers. From this study, the removal efficiency of microplastics from the water by using hydrophobic solvent was more than 80% in all experiments. The optimum removal efficiency of 86% was found at using 20 milliliters of hydrophobic solvent in 1 liter of wastewater that contains 100 milligrams of microplastics. Moreover, the removal efficiency of microplastics from the water by using electrolysis was excess than 90% in all experiments. The optimum separation efficiency of 97.99% was found at using 1 grams of sodium chloride in 1 liter of wastewater, that 100 milligrams of microplastics were contaminated.

However, the separation of microplastics from the water by using hydrophobic solvent and electrolysis have some disadvantage. The disadvantage of extraction by using hydrophobic solvent causes emulsion between hydrophobic and water. The disadvantage of electrolysis is contamination of aluminum ions. Therefore, the contamination from microplastics removal by using both techniques must be treated before discharging to the external source.

5.2 Suggestion

1) In order to correctly measure the amount of microplastics distribution in water, it is necessary to use other methods.

2) In the part of microplastics separation by using electrolysis, it is necessary to add other control variables such as the operating current, initial pH, surface area to volume ratio and electrode consumption.

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Appendix

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Appendix A: Properties of materials

A-1 Aluminum hydroxide ($Al(OH)_3$)

Figure A-1 Aluminum hydroxide ($Al(OH)_3$)

Table A-1 Properties of aluminum hydroxide ($Al(OH)_3$)

Properties	Value	Unit
Appearance	White amorphous powder	-
Density (Solid)	2.42	g/cm^3
Melting point	300	°C
Flash point	N/A	-
Solubility in water	0.001	g/L

A-2 Aluminum sheet (Al)

Figure A-2 Aluminum sheet (Al)

Table A-2 Properties of aluminum sheet (Al)

Properties	Value	Unit
Appearance	Silvery	-
Density	2.7	g/cm^3
Melting point	660.37	°C
Solubility in water	N/A	-
Electrical resistivity at 0 °C	2.6548	Microohm · cm

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A-3 Palm oil

Figure A-3 Palm oil

Table A-3 Density of palm oil at different temperature

Temperature (°C)	Density (kg/m^3)
20	890.10
25	887.50
30	885.00
35	882.50
40	880.00
45	877.50
50	875.10
55	872.60
60	870.20

A-4 Polyethylene powder

Figure A-4 Polyethylene powder

Table A-4 Properties of polyethylene powder used in this experiment

Properties	Value	Unit
Type of polyethylene	linear-low density polyethylene (LLDPE)	-
Color	Red	-
Density at 23 °C	0.90 – 0.97	g/cm^3
Melting point	120 - 130	°C
Solubility in water	Insoluble	-
Particle size	106 – 150	Micron (μm)

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A-5 Sodium chloride (NaCl)

Figure A-5 Sodium chloride (NaCl)

Table A-5 Properties of sodium chloride

Properties	**Value**	**Unit**
Color	White	-
Density	2.17	g/cm^3
Solubility in water	360	g/L
Lethal dose or concentration (LD_{50})	3	g/kg

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Appendix B: Experimental result and calculation

Table B-1 Result of microplastics separation from water by using hydrophobic solvent (Palm oil). All other reactor conditions: mixing speed of stirrer, 350 rpm; initial microplastics concentration, 0.1 g/L; and stirring speed, 60 rpm

No	Time	Palm oil (mL)	Microplastics {Before} (g/L)			Microplastics {After} (g/L)			% Removal (t = 0 min)			% Removal (Over all)		
			1	2	AV	1	2	Avg	1	2	Avg	1	2	Avg
1	0	0	0.1038	0.1026	0.1032	0.0821	0.0818	0.0820	0.00	0.00	0.00	20.83	20.26	20.54
	5					0.0519	0.0540	0.0529	36.88	34.00	35.44	50.02	47.37	48.70
	10					0.0310	0.0315	0.0312	62.26	61.52	61.89	70.12	69.32	69.72
	20					0.0208	0.0177	0.0193	74.64	78.36	76.50	79.92	82.74	81.33
	30					0.0190	0.0182	0.0186	76.87	77.78	77.32	81.69	82.28	81.98
2	0	5	0.1049	0.1101	0.1075	0.0700	0.0689	0.0694	0.00	0.00	0.00	33.27	37.49	35.38
	5					0.0456	0.0413	0.0434	34.84	40.06	37.45	56.52	62.53	59.52
	10					0.0256	0.0289	0.0273	63.49	57.96	60.72	75.64	73.72	74.68
	20					0.0146	0.0190	0.0168	79.17	72.45	75.81	86.10	82.78	84.44
	30					0.0120	0.0144	0.0132	82.80	79.02	80.91	88.53	86.89	87.71
3	0	10	0.1022	0.1067	0.1044	0.0616	0.0660	0.0638	0.00	0.00	0.00	39.72	38.08	38.90
	5					0.0400	0.0393	0.0396	35.07	40.51	37.79	60.86	63.16	62.01
	10					0.0255	0.0254	0.0254	58.62	61.54	60.08	75.06	76.19	75.62
	20					0.0160	0.0190	0.0175	73.97	71.28	72.62	84.31	82.22	83.26
	30					0.0130	0.0137	0.0134	78.90	79.22	79.06	87.28	87.13	87.20
4	0	15	0.1015	0.1076	0.1045	0.0560	0.0583	0.0572	0.00	0.00	0.00	44.81	45.76	45.28
	5					0.0367	0.0355	0.0361	34.52	39.22	36.87	63.86	67.03	65.45
	10					0.0208	0.0231	0.0219	62.94	60.44	61.69	79.54	78.54	79.04
	20					0.0179	0.0182	0.0181	67.99	68.83	68.41	82.33	83.09	82.71
	30					0.0150	0.0127	0.0139	73.21	78.18	75.70	85.22	88.17	86.69
5	0	20	0.1008	0.1069	0.1038	0.0500	0.0509	0.0504	0.00	0.00	0.00	50.40	52.38	51.39
	5					0.0316	0.0303	0.0310	36.84	40.39	38.62	68.67	71.62	70.15
	10					0.0205	0.0210	0.0208	58.93	58.72	58.83	79.63	80.35	79.99
	20					0.0135	0.0144	0.0140	72.92	71.61	72.26	86.57	86.48	86.52
	30					0.0127	0.0127	0.0127	74.58	74.98	74.78	87.39	88.09	87.74

Table B-2 Result of microplastics separation from water by using hydrophobic solvent (Palm oil). All other reactor conditions: mixing speed of stirrer, 700 rpm; initial microplastics concentration, 0.1 g/L; and stirring speed, 60 rpm

No	Time	Palm oil (mL)	Microplastics {Before}			Microplastics {After}			% Removal			% Removal		
			1	2	AV	1	2	AV	1	2	AV	1	2	AV
1	0	0	0.1038	0.1031	0.1034	0.0964	0.0978	0.0971	0.00	0.00	0.00	7.06	5.16	6.11
	5					0.0689	0.0675	0.0682	28.58	31.00	29.79	33.62	34.56	34.09
	10					0.0436	0.0448	0.0442	54.77	54.18	54.47	57.96	56.54	57.25
	20					0.0215	0.0273	0.0244	77.66	72.05	74.86	79.24	73.49	76.37
	30					0.0190	0.0183	0.0187	80.30	81.26	80.78	81.69	82.23	81.96
2	0	5	0.1081	0.1051	0.1066	0.0394	0.0365	0.0380	0.00	0.00	0.00	63.59	65.23	64.41
	5					0.0300	0.0227	0.0264	23.78	37.80	30.79	72.25	78.38	75.31
	10					0.0196	0.0180	0.0188	50.29	50.74	50.52	81.90	82.87	82.39
	20					0.0177	0.0167	0.0172	55.01	54.39	54.70	83.62	84.14	83.88
	30					0.0160	0.0151	0.0156	59.35	58.63	58.99	85.20	85.62	85.41
3	0	10	0.1031	0.1008	0.1019	0.0307	0.0323	0.0315	0.00	0.00	0.00	70.22	67.96	69.09
	5					0.0236	0.0215	0.0226	23.18	33.30	28.24	77.12	78.63	77.88
	10					0.0189	0.0190	0.0189	38.48	41.16	39.82	81.68	81.15	81.41
	20					0.0160	0.0180	0.0170	47.76	44.26	46.01	84.44	82.14	83.29
	30					0.0154	0.0149	0.0151	49.89	53.88	51.88	85.08	85.22	85.15
4	0	15	0.1015	0.1072	0.1044	0.0260	0.0268	0.0264	0.00	0.00	0.00	74.43	75.01	74.72
	5					0.0236	0.0200	0.0218	9.14	25.33	17.24	76.76	81.34	79.05
	10					0.0206	0.0173	0.0189	20.68	35.52	28.10	79.72	83.89	81.80
	20					0.0175	0.0160	0.0168	32.41	40.27	36.34	82.72	85.07	83.90
	30					0.0145	0.0149	0.0147	43.96	44.33	44.15	85.67	86.09	85.88
5	0	20	0.1026	0.1053	0.1039	0.0196	0.0220	0.0208	0.00	0.00	0.00	80.89	79.10	79.99
	5					0.0184	0.0181	0.0182	6.33	17.79	12.06	82.10	82.82	82.46
	10					0.0169	0.0157	0.0163	13.63	28.70	21.16	83.49	85.10	84.29
	20					0.0160	0.0140	0.0150	18.40	36.36	27.38	84.41	86.70	85.55
	30					0.0155	0.0135	0.0145	21.18	38.81	30.00	84.94	87.21	86.07

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Table B-3 The relation between concentration of sodium chloride with current

Concentration of sodium chloride (g/L)	I (Amp)	I_{cal} (Amp)	ΔI (Amp)
0.0000	0.00	0.00	0.00
0.0996	0.08	0.08	0.00
0.3351	0.22	0.27	0.05
0.5666	0.46	0.46	0.00
0.7882	0.64	0.64	0.00
1.0547	0.85	0.86	0.01
1.3404	1.08	1.09	0.01
1.4842	1.20	1.21	0.01
1.7102	1.38	1.39	0.01
1.9881	1.60	1.62	0.02
2.2510	1.83	1.84	0.01
2.5207	2.04	2.05	0.01
2.8286	2.30	2.31	0.01
2.9727	2.44	2.42	-0.02
3.1456	2.61	2.56	-0.05

Table B-4 The results of electrolysis in water. All other reactor conditions: mixing speed of stirrer, 350 rpm; voltage, 31.5 V; and stirring speed, 60 rpm

Time (min)	Salt (g/L)			I (Amp)			$Al(OH)_3$ (g/L)			Al Sheet (g)		
	1	2	AV	1	2	Avg	1	2	Avg	1	2	Avg
0	1.0095	1.0129	1.0112	0.85	0.85	0.85	0.0082	0.0082	0.0082	0.1736	0.1630	0.1683
5				0.80	0.84	0.82	0.0776	0.0815	0.0795	0.1133	0.1001	0.1067
10				0.81	0.81	0.81	0.1571	0.1571	0.1571	0.1200	0.1018	0.1109
20				0.81	0.81	0.81	0.3143	0.3143	0.3143	0.1406	0.1092	0.1249
30				0.81	0.80	0.81	0.4714	0.4656	0.4685	0.5475	0.4741	0.5108
0	2.0098	2.0150	2.0124	1.52	1.56	1.54	0.0147	0.0151	0.0149	0.3462	0.3144	0.3303
5				1.49	1.53	1.51	0.1445	0.1484	0.1465	0.2157	0.2043	0.2100
10				1.47	1.52	1.50	0.2852	0.2949	0.2900	0.2127	0.2017	0.2072
20				1.50	1.50	1.50	0.5820	0.5820	0.5820	0.2232	0.2096	0.2164
30				1.50	1.50	1.50	0.8730	0.8730	0.8730	0.9978	0.9300	0.9639
0	3.0386	3.0255	3.0321	2.39	2.37	2.38	0.0232	0.0230	0.0231	0.6295	0.4976	0.5635
5				2.47	2.45	2.46	0.2396	0.2376	0.2386	0.3933	0.3234	0.3584
10				2.47	2.45	2.46	0.4792	0.4753	0.4772	0.3949	0.3193	0.3571
20				2.49	2.47	2.48	0.9661	0.9583	0.9622	0.4435	0.3317	0.3876
30				2.49	2.47	2.48	1.4491	1.4375	1.4433	1.8612	1.4720	1.6666

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Table B-5 The results of electrolysis in water. All other reactor conditions: mixing speed of stirrer, 700 rpm; voltage, 31.5 V; and stirring speed, 60 rpm

Time (min)	Salt (g/L)			I (Amp)			$Al(OH)_3$ (g/L)			Al Sheet (g)		
	1	2	AV	1	2	Avg	1	2	Avg	1	2	Avg
0	1.0141	1.0230	1.0186	0.83	0.91	0.87	0.0000	0.0000	0.0000	0.1672	0.1833	0.1753
5				0.81	0.87	0.84	0.0002	0.0002	0.0002	0.1087	0.1192	0.1139
10				0.82	0.88	0.85	0.0004	0.0004	0.0004	0.1073	0.1176	0.1125
20				0.82	0.89	0.86	0.0008	0.0009	0.0008	0.1115	0.1222	0.1168
30				0.82	0.88	0.85	0.0012	0.0013	0.0012	0.4946	0.5423	0.5185
0	2.0436	2.0135	2.0286	1.47	1.46	1.47	0.0000	0.0000	0.0000	0.3166	0.2941	0.3054
5				1.40	1.41	1.41	0.0003	0.0003	0.0003	0.2019	0.1912	0.1965
10				1.37	1.43	1.40	0.0007	0.0007	0.0007	0.1931	0.1887	0.1909
20				1.42	1.43	1.43	0.0014	0.0014	0.0014	0.1883	0.1961	0.1922
30				1.42	1.43	1.43	0.0021	0.0021	0.0021	0.8999	0.8701	0.8850
0	3.0655	3.0020	3.0338	2.26	2.32	2.29	0.0001	0.0001	0.0001	0.5960	0.5674	0.5817
5				2.39	3.41	2.90	0.0006	0.0008	0.0007	0.4438	0.4038	0.4238
10				2.52	2.50	2.51	0.0012	0.0012	0.0012	0.4003	0.4099	0.4051
20				2.75	2.72	2.74	0.0027	0.0026	0.0027	0.4419	0.4116	0.4267
30				3.03	3.00	3.02	0.0044	0.0044	0.0044	1.8820	1.7926	1.8373

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Table B-6 Result of microplastics separation from water by using electrolysis. All other reactor conditions: mixing speed of stirrer, 350 rpm; initial microplastics concentration, 0.1 g/L; voltage, 31.5 V; and stirring speed, 60 rpm

No	Time (min)	Salt (g/L)			Microplastics (g/L)		I			$Al(OH)_3$ + Microplastics (g/L)		Microplastics (g/L)			%Removal (Over all)			Al Sheet (g)		
		1	2	Avg	1	2	1	2	Avg	1	2	1	2	Avg	1	2	Avg	1	2	Avg
1	0						0.92	0.90	0.91	0.0704	0.0704	0.0622	0.0621	0.0621	40.2926	38.0909	39.1917	0.1701	0.1818	0.1760
	5						0.88	0.89	0.89	0.0828	0.0838	0.0032	0.0042	0.0037	96.9041	95.8004	96.3523	0.1023	0.1028	0.1026
	10	1.0195	1.0139	1.0167	0.1041	0.1004	0.88	0.88	0.88	0.1602	0.1585	0.0031	0.0014	0.0022	97.0485	98.6458	97.8472	0.1032	0.1139	0.1086
	20						0.87	0.89	0.88	0.3143	0.3136	0.0000	-0.0007	-0.0003	99.9547	100.7014	100.3281	0.1036	0.1212	0.1124
	30						0.86	0.87	0.87	0.4709	0.4717	0.0024	0.0032	0.0028	97.6714	96.7855	97.2284	0.4792	0.5197	0.4995
2	0						1.52	1.49	1.51	0.0680	0.0648	0.0533	0.0501	0.0517	47.0608	53.0285	50.0447	0.3424	0.3419	0.3422
	5						1.51	1.47	1.49	0.1488	0.1483	0.0043	0.0038	0.0040	95.7672	96.4514	96.1093	0.2217	0.2196	0.2207
	10	2.0267	2.0149	2.0208	0.1006	0.1066	1.50	1.44	1.47	0.2891	0.2867	0.0039	0.0015	0.0027	96.0973	98.5911	97.3442	0.2126	0.2204	0.2165
	20						1.50	1.43	1.47	0.5840	0.5825	0.0020	0.0005	0.0013	97.9810	99.5018	98.7414	0.2234	0.2270	0.2252
	30						1.50	1.43	1.47	0.8730	0.8730	0.0000	0.0000	0.0000	99.9536	99.9563	99.9550	1.0001	1.0089	1.0045
3	0						2.29	2.30	2.30	0.0642	0.0633	0.0410	0.0402	0.0406	60.1314	62.6671	61.3992	0.4956	0.5526	0.5241
	5						2.31	2.35	2.33	0.2420	0.2430	0.0024	0.0034	0.0029	97.6432	96.8338	97.2385	0.3365	0.3776	0.3570
	10	3.0266	3.0193	3.0230	0.1028	0.1075	2.38	2.41	2.40	0.4811	0.4821	0.0020	0.0030	0.0025	98.0966	97.2213	97.6590	0.3324	0.3883	0.3604
	20						2.40	2.48	2.44	0.9670	0.9670	0.0009	0.0009	0.0009	99.0938	99.1338	99.1138	0.4326	0.4539	0.4433
	30						2.40	2.50	2.45	1.4481	1.4517	-0.0010	0.0026	0.0008	100.9284	97.6159	99.2722	1.5971	1.7724	1.6848

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Table B-6 Result of microplastics separation from water by using electrolysis. All other reactor conditions: mixing speed of stirrer, 700 rpm; initial microplastics concentration, 0.1 g/L; voltage, 31.5 V; and stirring speed, 60 rpm

No	Time (min)	Salt (g/L)			Microplastics (g/L)		I			$Al(OH)_3$ + Microplastics (g/L)		Microplastics (g/L)			%Removal			Al Sheet (g)		
		1	2	Avg	1	2	1	2	Avg	1	2	1	2	Avg	1	2	Avg	1	2	Avg
	0						0.85	0.82	0.84	0.0002	0.0002	0.0702	0.0716	0.0709	31.5640	29.3569	30.4605	0.1712	0.1652	0.1682
	5						0.82	0.80	0.81	0.0002	0.0002	0.0034	0.0032	0.0033	96.6569	96.8231	96.7400	0.1113	0.1074	0.1093
1	10	1.0223	1.0115	1.0169	0.1026	0.1013	0.83	0.79	0.81	0.0004	0.0004	0.0003	-0.0002	0.0001	99.7199	100.1829	99.9514	0.1099	0.1060	0.1079
	20						0.84	0.80	0.82	0.0008	0.0008	0.0007	-0.0014	-0.0003	99.3322	101.3476	100.3399	0.1142	0.1101	0.1121
	30						0.84	0.81	0.83	0.0012	0.0012	-0.0001	0.0009	0.0004	100.1249	99.0716	99.5982	0.5066	0.4887	0.4976
	0						1.57	1.44	1.51	0.0002	0.0002	0.0602	0.0572	0.0587	42.1317	43.9031	43.0174	0.3428	0.2901	0.3164
	5						1.52	1.43	1.48	0.0003	0.0003	0.0022	0.0020	0.0021	97.9022	98.0808	97.9915	0.2141	0.1886	0.2013
2	10	2.1369	2.0100	2.0735	0.1041	0.1020	1.55	1.42	1.49	0.0007	0.0007	-0.0002	0.0020	0.0009	100.1507	98.0398	99.0953	0.2097	0.1861	0.1979
	20						1.56	1.43	1.50	0.0014	0.0014	0.0008	-0.0009	-0.0001	99.1996	100.9288	100.0642	0.2126	0.1934	0.2030
	30						1.55	1.43	1.49	0.0021	0.0021	0.0007	0.0007	0.0007	99.3330	99.3193	99.3262	0.9792	0.8582	0.9187
	0						2.28	2.39	2.34	0.0002	0.0002	0.0501	0.0518	0.0509	52.2313	50.4656	51.3485	0.5484	0.5814	0.5649
	5						2.45	2.40	2.43	0.0007	0.0007	0.0017	0.0017	0.0017	98.3643	98.3596	98.3620	0.3701	0.4170	0.3935
3	10	3.0023	3.0390	3.0207	0.1049	0.1045	2.53	2.51	2.52	0.0012	0.0012	0.0013	0.0020	0.0016	98.7908	98.1110	98.4509	0.3556	0.4080	0.3818
	20						2.75	2.65	2.70	0.0027	0.0027	0.0009	-0.0001	0.0004	99.1285	100.1017	99.6151	0.3921	0.4273	0.4097
	30						2.90	2.97	2.94	0.0044	0.0044	0.0000	0.0004	0.0002	100.0346	99.5710	99.8028	1.6662	1.8337	1.7500

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Appendix C: Figure in this experiment

C-1 Separation of microplastics from water by using hydrophobic solvent

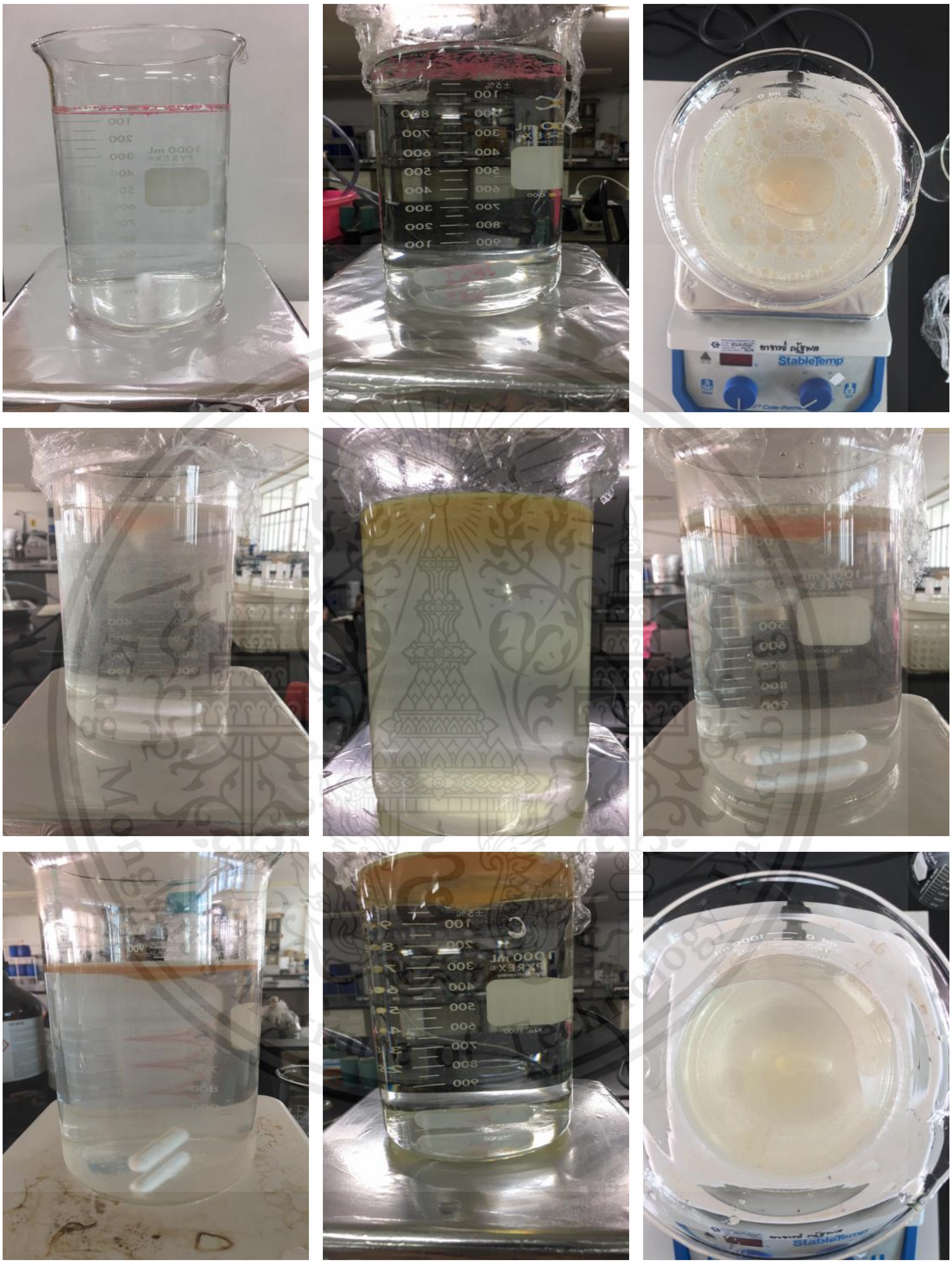

Figure C-1 Separation of microplastics from water with palm oil; different stirring speed and volume of palm oil

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C-2 Separation of microplastics from water by using electrolysis

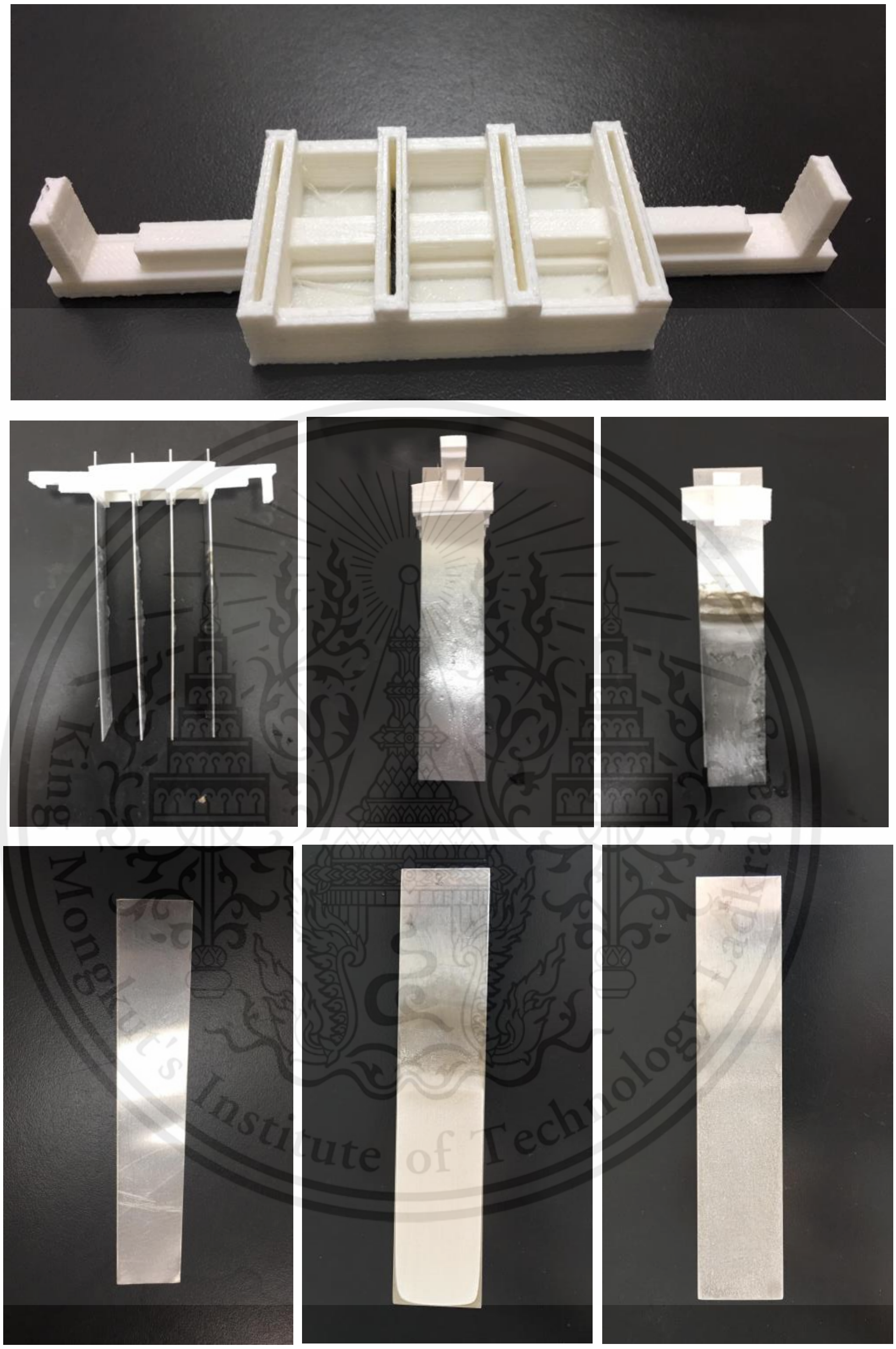

Figure C-2.1 Electrode and electrode holder used to separate microplastic

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Figure C-2.2 Separation of microplastics from water by using electrolysis; different stirring speed, current and concentration of NaCl

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