Utilization of Rain Tree (*Samanea saman*) Residue as Modified Adsorbent to Treat Oil and Grease in Canteen Wastewater

Miss Elga Riesta Puteri

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science in Hazardous Substance and Environmental Management
Inter-Department of Environmental Management
GRADUATE SCHOOL
Chulalongkorn University
Academic Year 2021

Copyright of Chulalongkorn University

การใช้ประโยชน์จากจามจุรี *(Samanea saman)* เป็นตัวดูดซับที่ผ่านการปรับปรุงเพื่อบำบัดน้ำมันและไขมันจากน้ำเสียโรงอาหาร

น.ส.เอลกา รีสตา ปูเตรี

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
สาขาวิชาการจัดการสารอันตรายและสิ่งแวดล้อม สหสาขาวิชาการจัดการสิ่งแวดล้อม
บัณฑิตวิทยาลัย จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2564
ลิขสิทธิ์ของจุฬาลงกรณ์มหาวิทยาลัย

Thesis Title	Utilization of Rain Tree (*Samanea saman*) Residue as Modified Adsorbent to Treat Oil and Grease in Canteen Wastewater
By	Miss Elga Riesta Puteri
Field of Study	Hazardous Substance and Environmental Management
Thesis Advisor	Associate Professor NUTA SUPAKATA, Ph.D.
Thesis Co Advisor	Assistant Professor Vorapot Kanokkantapong, Ph.D.

Accepted by the GRADUATE SCHOOL, Chulalongkorn University in Partial Fulfillment of the Requirement for the Master of Science

..... Dean of the GRADUATE SCHOOL
(Associate Professor YOOTTHANA CHUPPUNNARAT, Ph.D.)

THESIS COMMITTEE

..... Chairman
(Associate Professor MANASKORN RACHAKARAKIJ, Ph.D.)

..... Thesis Advisor
(Associate Professor NUTA SUPAKATA, Ph.D.)

..... Thesis Co-Advisor
(Assistant Professor Vorapot Kanokkantapong, Ph.D.)

..... Examiner
(Vacharaporn Soonsin, Ph.D.)

..... External Examiner
(Associate Professor Pongsak Noophan, Ph.D.)

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

เอลกา รีสตา ปูเตรี : การใช้ประโยชน์จากจามจุรี *(Samanea saman)* เป็นตัวดูดซับที่ผ่านการปรับปรุงเพื่อบำบัดน้ำมันและไขมันจากน้ำเสียโรงอาหาร. (Utilization of Rain Tree (*Samanea saman*) Residue as Modified Adsorbent to Treat Oil and Grease in Canteen Wastewater) อ.ที่ปรึกษาหลัก : นุตา ศุภคต, อ.ที่ปรึกษาร่วม : วรพจน์ กนกกันฑพงษ์

การใช้วัสดุเหลือทิ้งเป็นตัวดูดซับกำลังได้รับนิยมในการบำบัดน้ำมันและไขมัน (FOG) โดยเฉพาะอย่างยิ่งในการบำบัดน้ำเสีย ซึ่งเศษกิ่งไม้และใบไม้เป็นของเหลือทิ้งที่มีอยู่มากมายสามารถสร้างเป็นวัสดุที่มีคุณค่าได้ งานวิจัยนี้มีวัตถุประสงค์เพื่อพัฒนาตัวดูดซับที่ผ่านการปรับปรุงจากเศษกิ่งและใบของต้นจามจุรี *(Samanea saman)* เพื่อบำบัดน้ำมันและไขมันจากน้ำเสียโรงอาหาร โดยการสังเคราะห์ตัวดูดซับที่ผ่านการปรับปรุงด้วยการปรับสภาพทางเคมีด้วยโซเดียมไฮดรอกไซด์ ซิงค์คลอไรด์ และกรดฟอสฟอริก โดยมีอัตราส่วนของกิ่งและใบจามจุรีที่ 1:4 และผ่านกระบวนการไพโรไลซิสที่อุณหภูมิ 350 550 และ 750 องศาเซลเซียส โดยใช้อัตราการให้ความร้อน 10 องศาเซลเซียสต่อนาที เป็นเวลา 2 ชั่วโมง การทดสอบตัวดูดซับที่ผ่านการปรับปรุงแบบกะ เพื่อบำบัดน้ำมันและไขมันจากน้ำเสียที่มีน้ำมันสังเคราะห์ และใช้สถิติ ANOVA เพื่อศึกษาตัวดูดซับที่ผ่านการปรับปรุงที่ดีที่สุด ผลการศึกษาพบว่า ตัวดูดซับที่ผ่านการปรับปรุงด้วยกรดฟอสฟอริก ที่อุณหภูมิ 350 องศาเซลเซียส มีประสิทธิภาพสูงสุดในการกำจัดน้ำมันและไขมัน โดยให้ผลผลิตและการกำจัดคิดเป็นร้อยละ 55.87 ± 1.40 และ 79.77 ± 1.17 ตามลำดับ การศึกษาการดูดซับของตัวดูดซับที่ผ่านการปรับปรุงที่ดีที่สุดบ่งชี้ว่าสอดคล้องกับแบบจำลองจลนศาสตร์อันดับสองเทียม และไอโซเทอร์มของแลงเมียร์ โดยความสามารถในการดูดซับน้ำมันและไขมันสูงสุดอยู่ที่ 6.89 มิลลิกรัมต่อกรัม ผลจากการวิเคราะห์ FTIR แสดงให้เห็นถึงกลุ่มคาร์บอนิล (carbonyls) ไฮดรอกซิล (hydroxyls) และอะลิฟาติก (aliphatic) ภาพจาก Scanning Electron Microscope (SEM) แสดงให้เห็นโครงสร้างของรูพรุนบนพื้นผิว การทดสอบประสิทธิภาพของตัวดูดซับที่ผ่านการปรับปรุงที่ดีที่สุดด้วยวิธีคอลัมน์ ที่ความสูงของคอลัมน์ 10 เซนติเมตร และอัตราการไหล 5 มิลลิลิตรต่อนาที ในการบำบัดน้ำมันและไขมันจากน้ำเสียโรงอาหาร อย่างไรก็ตาม ไม่สามารถระบุจุดดูดซับเริ่มหมดประสิทธิภาพได้ เนื่องจากการอุดตันของคอลัมน์เมื่อเวลาผ่านไป 12 ชั่วโมง บทสรุปโดยภาพรวมจากผลการศึกษานี้พบว่าเศษกิ่งและใบของต้นจามจุรีที่ผ่านการปรับปรุงแล้วสามารถใช้เป็นตัวดูดซับทางเลือกในบำบัดน้ำมันและไขมันจากน้ำเสียโรงอาหารได้

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

สาขาวิชา	การจัดการสารอันตรายและสิ่งแวดล้อม	ลายมือชื่อนิสิต .....
ปีการศึกษา	2564	ลายมือชื่อ อ.ที่ปรึกษาหลัก .....
		ลายมือชื่อ อ.ที่ปรึกษาร่วม .....

6288520720 : MAJOR HAZARDOUS SUBSTANCE AND ENVIRONMENTAL MANAGEMENT
KEYWORD: Rain tree (Samanea Saman), Chemical pretreatment, Oily wastewater

Elga Riesta Puteri : Utilization of Rain Tree (*Samanea saman*) Residue as Modified Adsorbent to Treat Oil and Grease in Canteen Wastewater. Advisor: Assoc. Prof. NUTA SUPAKATA, Ph.D. Co-advisor: Asst. Prof. Vorapot Kanokkantapong, Ph.D.

The utilization of waste materials as adsorbent precursors is gaining intention to treat fats, oils, and greases (FOG), especially in wastewater treatment. Tree residue, an abundant waste, provides a potential feedstock to be converted into valuable materials. This research aimed to develop modified adsorbent prepared from rain tree *(Samanea saman)* residue for FOG treatment. The synthesis process of modified adsorbent was conducted by chemical pretreatment using different chemical agents (i.e., NaOH, $ZnCl_2$, and H_3PO_4). The pre-treated twigs and leaves (1:4 ratio) were continued by pyrolysis process at different temperatures (i.e., 350, 550, and 750^{o}C) using a heating rate of 10^{o}C min^{-1} for 2 h. A batch sorption screening test was initially conducted for removing FOG from synthetic oily wastewater, and the ANOVA was employed to define the best-modified adsorbent among treatments. The result confirmed that modified adsorbent by H_3PO_4-treated and produced at 350^{o}C had the highest net efficiency of FOG removal, with a yield and removal percentage of 55.87±1.40 and 79.77±1.17%, respectively. The adsorption studies of the best-modified indicated that the pseudo-second-order kinetic and Langmuir isotherm models were well-fitted to the experiment data. The maximum adsorption capacity of FOG was found to be 6.89 mg g^{-1}. Fourier transform infrared spectroscopy (FTIR) result exhibits the present carbonyls, hydroxyls, and aliphatic groups. Scanning Electron Microscope (SEM) image showed the porous structure on the surface. The subsequent identification of the best-modified adsorbent was carried out by fixed-bed column test and performed optimum condition for canteen wastewater treatment by setting 10 cm bed height and flow rate 5 ml min^{-1}. However, the breakthrough point could not be identified due to the column clogging (12 h). Overall, modified adsorbents produced had the ability to remove FOG, which indicated that rain tree residue could be utilized as an alternative adsorbent precursor for FOG treatment.

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

Field of Study:	Hazardous Substance and Environmental Management	Student's Signature .....
Academic Year:	2021	Advisor's Signature .....
		Co-advisor's Signature .....

ACKNOWLEDGEMENTS

I would like to acknowledge my advisors, Assoc. Prof. Nuta Supakata, Ph.D. and Asst. Prof. Vorapot Kanokkantapong, Ph.D., for their guidance, support, and opportunity for me to do this research on the topic of utilization of rain tree (Samanea saman) residue as modified adsorbent to treat oil and grease in canteen wastewater.

I also gratefully thank the members of my research committee, Assoc. Prof. Manaskorn Rachakarakij, Vacharaporn Soonsin, Ph.D., and Assoc. Prof. Pongsak Noophan, Ph.D., for their best advice and times.

I would like to express my sincere thanks to all staff members, all students in International Program in Hazardous Substance and Environmental Management (IP-HSM), and Environmental Science Department, Chulalongkorn University, for their valuable suggestions, assistance, supports, and warm relationship. Also, thanks to Indonesian students in Bangkok for their friendship and support during my study.

I acknowledge my gratitude to the Graduate School of Chulalongkorn University, which provided me the opportunity for the ASEAN Scholarship and Indonesian Agricultural Environment Research Institute (IAERI) in Indonesian Ministry of Agriculture to support my M.Sc. degree study.

Last but not least, heartfelt thanks to my family for their endless support, encouragement, and love.

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

Elga Riesta Puteri

TABLE OF CONTENTS

Page

ABSTRACT (THAI) iii

ABSTRACT (ENGLISH) iv

ACKNOWLEDGEMENTS v

TABLE OF CONTENTS vi

LIST OF TABLES ix

LIST OF FIGURES x

CHAPTER 1 1

INTRODUCTION 1

1.1 Introduction 1

1.2 Research objectives 5

1.3 Research hypotheses 5

1.4 Scope of study 6

CHAPTER 2 8

LITERATURE REVIEWS 8

2.1 Canteen wastewater 8

2.2 Treatment technologies for FOG 9

2.3 Utilization of tree residue as adsorbents' precursors 10

2.4 Rain tree *(Samanea saman)* 12

2.5 Chemical pretreatment 13

Alkaline treatment 14

Acid treatment 15

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Ionic liquid treatment 15
2.6 Pyrolysis process 17
2.7 Interaction of FOG uptake with adsorbent 19
CHAPTER 3 20
MATERIALS AND METHODS 20
3.1 Research materials 20
3.1.1 Material 20
3.1.2 Equipment 20
3.1.3 Chemicals 21
3.2 Experimental procedure 21
3.2.1 Part I: Modified adsorbent production 21
3.2.2 Part II: FOG treatment 23
Batch sorption test 23
FOG analysis 26
Characterization of rain tree (Samanea saman) biomass and best-modified adsorbent 27
Fixed-bed column test 28
3.2.3 Part III: Technology implementation 29
CHAPTER 4 30
RESULT AND DISCUSSION 30
4.1 Part I: Modified adsorbent production 30
4.1.1 Modified adsorbent yields and bulk densities 30
4.2 Part II: FOG treatment 32
4.2.1 Preliminary experiment on FOG treatment 32

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Batch sorption experiment 32
Analysis Zinc (Zn) in the treated synthetic emulsified oil wastewater 35
Net efficiency of FOG removal 36
4.2.2 Characterization of adsorbents 37
Proximate and ultimate analyzes 37
Thermogravimetry analysis of the precursor (rain tree residue) 39
Surface analysis 40
Scanning electron microscopy (SEM) 42
Fourier transform infrared spectroscopy (FTIR) 43
4.2.3 Adsorption studies of FOG removal 44
Adsorption kinetic study 44
Adsorption isotherm study 47
Fixed-bed column experiment 50
1) Canteen wastewater identification 50
2) Fixed-bed column test 51
4.3 Part III: Technology implementation 55
4.3.1 Economic feasibility analysis 55
5.1 Conclusions 60
5.2 Recommendations 60
REFERENCES 62
VITA 92

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

LIST OF TABLES

		Page
Table 2.1	Building Effluent Standards for food centers in Thailand (Environment, 2005)	9
Table 2.2	Tree residue as adsorbents' precursors	11
Table 2.3	Results of adsorption in oil-water emulsions or wastewater reported in the literature	16
Table 4.1	The yield and bulk density of modified adsorbents	32
Table 4.2	Application of different adsorbents for FOG removal	34
Table 4.3	Atomic absorption spectroscopy (AAS) analysis of Zn after FOG treatment using SAC350	36
Table 4.4	Elemental component (%wt) of some raw materials for adsorbent	38
Table 4.5	Proximate and ultimate analyzes of raw material and AAC350	39
Table 4.6	The methylene blue and iodine number analysis result	41
Table 4.7	Adsorption kinetic models for the adsorption of FOG on AAC350	47
Table 4.8	Adsorption isotherm models for the adsorption of FOG on AAC350	49
Table 4.9	Characterization of dormitory canteen wastewater compared with Type D (area size 100-250 m^2) building effluent standards for food centers in Thailand	51
Table 4.10	Capacity of machines used for AAC350 production calculations	56
Table 4.11	Calculation of economic feasibility for AC350 production from rain tree residue biomass	56

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

LIST OF FIGURES

		Page
Figure 2.1	Lignocellulose	11
Figure 2.2	Schematic representation of the effect of pretreatment on lignocellulosic biomass structure	14
Figure 2.3	Mechanism of FOG adsorption on carbon-based adsorbent (Ahmad et al., 2014)	19
Figure 3.1	Modified adsorbents production scheme	23
Figure 3.2	Batch sorption experiment scheme	26
Figure 3.3	Fixed-bed column test scheme	28
Figure 4.1	FOG removal by different adsorbents (Adsorbent dose 3 g in 200 mL of 50 mg/L synthetic emulsified oil wastewater, contact time 24 h)	35
Figure 4.2	Net efficiency of FOG removal by different adsorbents	37
Figure 4.3	TG/DTG Rain tree residue analysis	40
Figure 4.4	SEM images of (a) rain tree biomass (b) AAC350	42
Figure 4.5	FTIR spectrum of the rain tree biomass and AAC350	44
Figure 4.6	Effect of contact time on the adsorption of FOG onto AAC350	45
Figure 4.7	(a) Pseudo-first-order model (b) Pseudo-second-order model for adsorption of FOG on AAC350	47

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

Figure 4.8	Effect of initial concentration on the adsorption of FOG onto AAC350	48
Figure 4.9	(a) Langmuir adsorption isotherm of FOG on AAC350 (b) Freundlich adsorption isotherm of FOG on AAC350	49
Figure 4.10	Fixed packed column experiment set	52
Figure 4.11	The FOG removal in the fixed bed column (Bed height 10 cm, flow rate 5 mL/min, concentration of canteen wastewater 50 mg/L)	53
Figure 4.12	The FOG removal in the fixed bed column (Bed height 10 cm, flow rate 10 mL/min, concentration of canteen wastewater 50 mg/L)	53
Figure 4.13	The FOG removal in the fixed bed column (Bed height 5 cm, flow rate 10 mL min-1, concentration of canteen wastewater 50 mg L-1)	54
Figure 4.14	Process flow diagram to produce modified adsorbent from rain tree residue	55

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

CHAPTER 1
INTRODUCTION

1.1 Introduction

Canteens generate wastewater from the water that has been used for food preparation and cleaning activities. The effluent is usually heavily loaded with organic matters from cooking oil, oily flavorings, and food leftovers. Among many organic pollutants, one regularly found in canteen wastewaters is fat, oil, and grease (FOG). FOG is a group of organic substances with a very low affinity to water (Pintor et al., 2016). The high concentration of FOG in the wastewater tends to clog the sewer system and generates an unpleasant odor. Most importantly, it becomes a threat to aquatic organisms due to the decreasing oxygen transfer into the water (Abass, 2011). Furthermore, the direct discharge of oily wastewater to sewage will cause an extra burden to the municipal wastewater treatment. For the aforementioned impacts, FOG has become one of the significant water pollution fountainheads.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

The treatment of FOG in wastewater involves a combination of different treatments. It generally consists of a primary treatment followed by secondary treatment, and tertiary treatment is commonly carried out to refine or reuse the wastewater. The primary treatment involves a gravity separation tank with a stagnant flow allowing oil to float on the surface, and the secondary treatment aims to remove the remaining oil consisted of the emulsified form. The emulsified form of

FOG removal remains a challenge in the secondary treatment since the gravity separation is ineffective (Zouboulis and Avranas, 2000). One of the promising technologies for FOG treatment is adsorption. A cost-effective and straightforward adsorption method with highly effective adsorption capacity is required to remove FOG from the wastewater (Kandanelli et al., 2018; Lam et al., 2018; Sohaimi and Ngadi, 2016). Carbonaceous materials are commonly used adsorbents in wastewater treatment. The carbon-based adsorbents have been extensively examined possessing high surface area, large porosity, and active sites for contaminant adsorption (Gusain et al., 2019; Kumar et al., 2019).

Many researchers have developed carbon-based adsorbents from inexpensive materials (González-García, 2018), and interestingly, adsorbent prepared from waste biomass has gained attention with its economic value as an available adsorbent for oily wastewater treatment (Mohan et al., 2014; Zhang et al., 2019). Several studies have utilized lignocellulosic material to produce affordable adsorbent and applied it for water pollutant removal (Hu et al., 2019; Kim et al., 2020; Sahota et al., 2018). The materials can be from various solid wastes (e.g., rice husk, cork, seedpods, corncob, fruit peels, and leaves) (Enniya et al., 2018; Liu et al., 2020; Mian and Liu, 2020).

Some studies have selected tree residue as an adsorbent precursor for organic and inorganic contaminant removal in the wastewater. The notable features of the tree residue in terms of porosities and surface functional groups for producing

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

adsorbent, the possibility of mass production at low cost, and the resolution of the waste disposal problem with the addition of value-added products can be justified as adsorbent precursor selection. For instance, a maple leaf-based adsorbent has been employed for tetracycline removal by providing a significant increase in hydrophobicity and surface area by pyrolysis process that facilitate the contaminant uptake (Derakhshan-Nejad and Jung, 2018).

There are numerous perennial plants in Thailand, and Chulalongkorn University is one of the homes of the prominent perennial plant named rain tree (*Samanea saman*). It has rough bark, grayish-brown with horizontal lines, and bi-pinned leaves. The trees lose their leaves in a short time (Denia C. Delgado, 2016) and shed massive leaves, twigs, even branches in Chulalongkorn University's campus throughout the year, and their residues are considered solid waste. Approximately, one ton of rain tree residue is collected around campus area daily and currently, only some portions of rain tree residue are converted as compost, whereas the remaining amount is converted as livestock or disposed to landfills. The lignocellulosic component in the rain tree (*Samanea saman)* residue can be employed as a precursor for developing adsorbent; therefore, rain tree (*Samanea saman*) usage as available biomass could considerably become alternative way for its disposal. Accordingly, in this study, rain tree residue was selected as the raw material for the adsorbent production.

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

The capability of adsorbent depends on the materials' characteristics and the preparation process (Elsayed et al., 2017). Most of natural adsorbents suffer drawback in term of hydrophobicity characteristic. The FOG as the target pollutant has high hydrophobicity. Thus, the low hydrophobicity of natural adsorbent reduces the effectiveness to adsorb oil due to high water uptake (Wake, 2005). Other adsorption factors related to the surface area, pore size, molecular weight, hydrophobicity, polarity, and functional groups of the adsorbent (Azargohar and Dalai, 2008). Thus, in this study, modification of rain tree residue has been observed in order to enhance its properties for increasing oil removal efficiency. The modification processes have been carried out by chemical pretreatment and followed by pyrolysis. Some studies reported that chemical treatment before pyrolysis obtains high porosity, high yield, and less damaged surface (Maciá-Agulló et al., 2004). Chemical pretreatments of biomass have been studied, such as impregnation with acid, base, or ionic solutions. The different type of chemical treatments disrupts the complex structure of lignocellulosic component by various mechanism resulting improved surface area and pore formation (Yuan et al., 2020). These obtained modified adsorbent have been applied in the oily wastewater treatment and proved to increase the FOG removal in wastewater due to improved properties of modified adsorbent (Ngarmkam et al., 2011; Pintor et al., 2013; Santos et al., 2020). This study aimed to prepare and characterize of modified adsorbent obtained from rain tree (*Samanea saman*) residue by chemical treatment using NaOH, H_3PO_4, and $ZnCl_2$ followed by

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

pyrolysis. The prepared modified adsorbents were investigated its potential for FOG treatment in canteen wastewater.

1.2 Research objectives

The main objective of this study is to develop modified adsorbent prepared from rain tree (*Samanea saman)* residue for FOG treatment in canteen wastewater. Three sub-objectives are as follows.

1. To utilize rain tree *(Samanea saman)* residue as modified adsorbent precursor by chemical pretreatments using NaOH, H_3PO_4, and $ZnCl_2$ and pyrolysis process.
2. To investigate the potential of modified adsorbent prepared from rain tree *(Samanea saman)* residue by batch experiment for FOG in synthetic emulsified oil wastewater.
3. To subsequently investigate the potential of modified adsorbent prepared from rain tree *(Samanea saman)* residue by fixed-bed column tests for FOG removal in canteen wastewater.

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

1.3 Research hypotheses

1. Chemical pretreatment (NaOH, H_3PO_4, and $ZnCl_2$) followed by pyrolysis of rain tree (*Samanea saman)* residue are expected to increase modified adsorbents' sorption capability for FOG compared with natural adsorbent.

2. Modified adsorbent prepared from rain tree *(Samanea saman)* residue is an alternative adsorbent material for FOG treatment.
3. Fixed-bed column test can be used to evaluating the efficiency of the best-modified adsorbent from rain tree *(Samanea saman)* residue for FOG treatment process on the pilot scale.

1.4 Scope of study

This study was divided into three main parts: modified adsorbent production, FOG treatment, and technology implementation. For the first part, modified adsorbent production from rain tree (*Samanea saman*) residue was carried out by varying chemical pretreatments (NaOH, H_3PO_4, and $ZnCl_2$) and pyrolysis temperatures (350°C, 550°C, and 750°C). After the modified adsorbents were produced, all modified adsorbents were investigated its adsorption capacity for FOG in synthetic emulsified oil wastewater. Next, the modified adsorbent with the greatest adsorption performance was determined for adsorption isotherm and isotherm kinetic by batch sorption; it was also continuously examined using a fixed-bed column experiment for canteen wastewater. Finally, the best-modified adsorbent was selected for economic feasibility analysis for technology implementation (**Figure 1.1**).

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

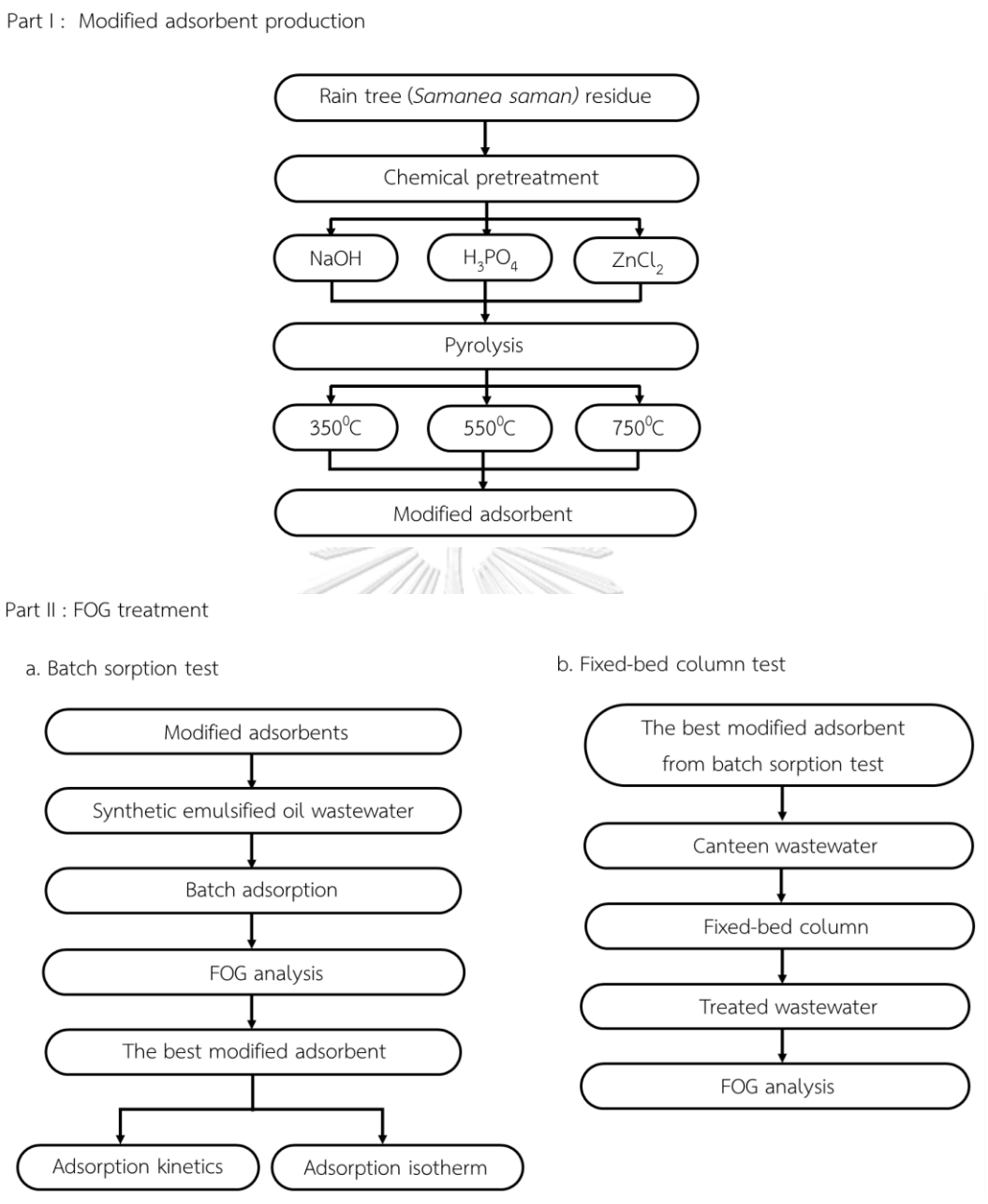


Figure 1.1 Overview of the study

CHAPTER 2
LITERATURE REVIEWS

2.1 Canteen wastewater

There are two categories of domestic wastewater: black water and greywater. They are classified based on the source at the household scale (Boutin and Eme, 2016). Generally, black water produced from flush water or toilet ended at the septic tank system. Meanwhile, greywater contains high turbidity phosphorus, total suspended solids, oil and grease, and surfactant from food cleaning and personal care products (Chrispim and Nolasco, 2017). Refers to the classification, canteen wastewater produced from food processing is categorized as greywater.

Canteen wastewater usually has a high value of fat, oil, and grease (FOG), biological oxygen demand (BOD), and chemical oxygen demand (COD) due to the existence of organic matters. FOG in the massive amount results in foul odor and sewage blockage (Brooksbank et al., 2006). FOG consists of fatty acids and glycerol that are not easily degraded and remove from the water and has a density less than water (density <1), and thus, it floats on the water surface (Matsumiya et al., 2007). The range of value of foodservice wastewater varies from 545-1630 mg L^{-1} of BOD, 124-1320 mg L^{-1} of Total Suspended Solid (TSS), and 415-1970 mg L^{-1} of FOG (Lesikar et al., 2006). Based on the building effluent standard, the maximum permitted value from the food center (size area more than 100 m^2) is shown in Table 1. Therefore,

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

many researchers have stepped up efforts to find alternative solutions in order to treat FOG in the wastewater before directly discharging it to sewages.

Table 2.1 Building effluent standards for food centers in Thailand (Environment, 2005)

Parameter	Unit	Range or Maximum Permitted Value
pH	-	5-9
BOD	mg L^{-1}	50
TSS	mg L^{-1}	50
FOG	mg L^{-1}	20

2.2 Treatment technologies for FOG

Treatment of oily wastewater consists of a primary treatment followed by a second step and, when needed, a tertiary stage to refine quality parameters for discharge or reuse. The primary treatment generally consists of a gravity separation tank, allowing free oil to float to the water surface, and the solid contents will settle down in the quiescence condition. The separation principle involves gravity force and difference in oil and water densities (Ahmad et al., 2005; Kamal Al-Malah, 2000). The wastewater from primary treatment goes to the secondary treatment that aims to separate the remaining oil, and mainly it occurs in the emulsified form and could not be separated under gravity separation. This type of FOG needs to be treated at the secondary treatment after gravity separation.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

The breaking of oil emulsion can be carried out chemically, physically, or electrically treatments. Interestingly, the adsorption process is a favorable physicochemical method for removing FOG in wastewater systems, among other chemical and physical methods nowadays (Sohaimi and Ngadi, 2016). The economical alternative source materials of adsorbent drive the broad application of this method. There are some advantages of employing adsorption to treat oily wastewater, i.e., high removal efficiency, cheap (especially with low-cost materials), ease of operation, the possibility of regeneration (Wahi et al., 2013). Thus, a low-cost and straightforward technology using waste materials and by-products from agriculture to produce adsorbent is gaining focus among researchers to treat FOG in wastewater.

2.3 Utilization of tree residue as adsorbents' precursors

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Tree residue, an abundant waste, provides a potential feedstock to be converted into valuable materials. The tree residues are usually disposed of by landfilling, open burning, and composting. These tree residues generated as solid waste in large amounts can be utilized for further use than disposed of by those impractical conventional methods. Typically, biomass (plants and trees) comprises three components: cellulose, hemicellulose, and lignin. These components are firmly linked, chemically bonded by non-covalent forces, and cross-linked together,

thereby providing structure and rigidity as shown in **Figure 2.1** (Kambo and Dutta, 2015).

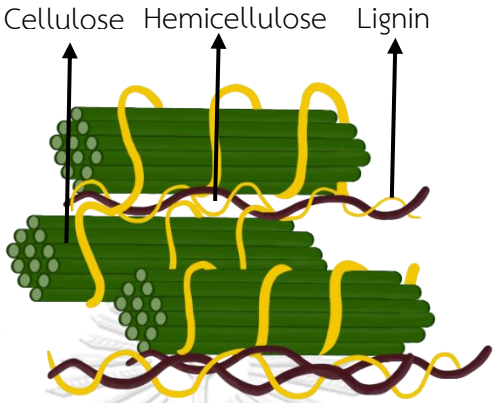


Figure 2.1 Lignocellulose

Table 2.2 Tree residue as adsorbents' precursors

Adsorbent	Material	Pollutant	Ref.
Biochar	Ginkgo leaves	Pb and Cu	(Lee et al., 2017)
Biochar	Maple leaves (*Acer palmatum Thunb.*)	Tetracycline	(Kim et al., 2020)
Biochar	Fallen leaves	H_2S	(Sahota et al., 2018)
Biochar	*Magnolia grandiflora Linn* Fallen Leaves	Methylene blue	(Ji et al., 2019)
Biochar	Walnut leaves (*Juglans regia L.*)	Pb and Zn	(Kabiri et al., 2019)
Activated carbon	Camphor leaves (*Cinnamomum bodinieri*)	Ciprofloxacin	(Hu et al., 2019)
Activated carbon	Coconut leaves	Methylene blue	(Rashid et al., 2016)

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

The lignocellulosic composition of biomass has a strong influence on hydrophobic behavior. Among the lignocellulosic biomass compositions, hemicellulose has the most significant water adsorption capacity (Acharjee et al., 2011). Hence, removing the lignocellulosic component will improve its hydrophobicity that contribute to oil removal efficiency. Thus, carbon-based adsorbent prepared from tree residue is a promising adsorbent as it is cheap and provides some impressive properties for contaminant removal, especially FOG.

2.4 Rain tree *(Samanea saman)*

Samanea saman or rain tree is extensively cultivated worldwide, specifically in tropical and subtropical countries. The native of rain tree is Central America and Northern South America (Magnus and Seaforth, 1965) and widespread in Thailand (Sareena Semae and Somchai Chanpongsang, 2013). The tree can reach until 25 meters high that the top of the tree forms like an umbrella with abundant foliage. Rain tree has rough and pale gray to brownish bark (Evans, 2006). During the dry periods, trees shed their leaves in a short time. Rain tree offers excellent shade, wood, and pods containing lignocellulosic components. Although this tree outstands among agroforestry species, there is a lack of information available supporting its potentialities.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

The fresh leaves of rain tree contain 34% dry matter, 30% crude protein, 29% fiber, and 3.5% ash (Gohl, 1981). Meanwhile, the twigs contain 38.9% dry matter,

24.7% crude protein, 22.1% fiber, and 3.5% ash. A study has identified *Samanea saman* for animal feedstock and found that it contains more than 25% lignocellulosic components presented as neutral and acid detergent fiber fraction (Delgado et al., 2016). Due to the aforementioned lignocellulosic components containing, more studies related to its properties are required to explore to confirm the potential of rain tree residue as an alternative and effective adsorbent precursor.

2.5 Chemical pretreatment

Modified adsorbent properties depend on the characteristics of the biomass and the conditions of the production process. Modification of adsorbent can significantly increase the surface area due to the development and opening of the internal porous structure of a biomaterial (Gratuito et al., 2008). The most common methods for adsorbent treatment is chemical treatment (Lehmann and Joseph, 2012). The choice of the treatment is a crucial part for modified adsorbent.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Chemical treatment has a number of advantages, including the following: it involves low temperatures, large surface area, and fast conversion. Moreover, chemical activation offers a good pore distribution and consumes less energy (Beltrame et al., 2018; Nowicki et al., 2015; Romero-Anaya et al., 2014; Shamsuddin et al., 2016). Chemical treatment is typically performed using several pretreatments of the biomass that improve its sorption performance. It has been studied by washing the biomass with solvents, soaking in salt, acid, or base solutions (Beltrame

et al., 2018; Castro et al., 2020; Ma, 2016; Menya et al., 2018). During chemical treatment, the chemical separates the lamellae of crystallites, forming its monomers (**Figure 2.2**). After rinsing with water, activators are washed away, leaving behind a structure with highly improved surface area and porosity (Januszewicz et al., 2020).

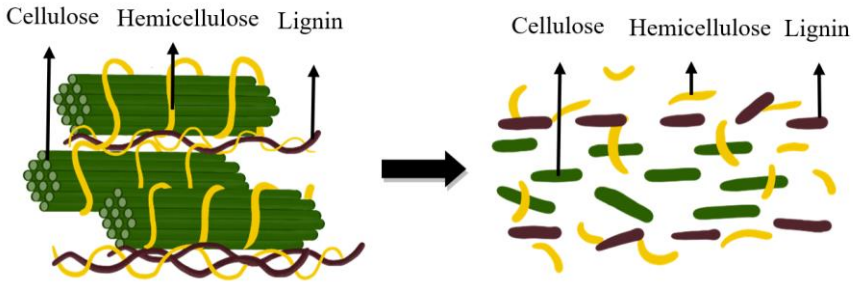


Figure 2.2 Schematic representation of the effect of pretreatment on lignocellulosic biomass structure

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Alkaline treatment

The various alkaline reagents commonly used for alkali pretreatment are the hydroxides of sodium, potassium, calcium, and ammonium. Among these alkaline, sodium hydroxide (NaOH) was found to be the most effective (Kim, 2018). A study reported that NaOH activation, compared with KOH activation, has advantages such as lower dosage, cheaper, more environmentally friendly, and less corrosive (Tseng, 2006). A saponification reaction occurs throughout the alkali pretreatment that causes breaking down of the intermolecular ester linkages between hemicelluloses

and lignin (Sun et al., 2016). Alkali pretreatment changes the lignocellulosic structure via cellulose swelling, leading to a reduction in crystallinity and degree of polymerization, thereby increasing internal surface area (Behera et al., 2014).

Acid treatment

Acid pretreatment of lignocellulosic material is based on the susceptibility of the glycosidic linkage between hemicellulose and cellulose to acid. Hydronium ions from the acid activator cause breakdown of the long cellulose and hemicellulose chains into sugar monomers (Lloyd and Wyman, 2005). Some acids such as H_2SO_4 (Karcher et al., 2015), H_3PO_4 (Hadoun et al., 2013), HNO_3 (Su et al., 2019), and HCl (Zu et al., 2014) are usually employed. However, H_3PO_4 is preferable chemical treatment due to its lower corrosive property compared to other acids.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Ionic liquid treatment

Chemical treatment that also usually employed for biomass pretreatment is ionic compounds. It comprises anion and cation that play an important role in solubilizing the lignocellulosic components. Impregnation with ionic activator affects carbonization, dehydration, degradation of lignocellulose. As a result, it facilitates the pyrolysis process, creates pore structure, and aromatization in carbon (Angin, 2014). Zinc chloride ($ZnCl_2$) is highly effective and frequently used as chemical pretreatment. The Zn^{2+} ions distribute to the amorphous and crystalline structure of

biomass causing the fiber swelling. Thus, it simplifies the complex structure of lignocellulosic content in the biomass (Yang et al., 2011).

Many researchers have investigated various adsorbent for FOG removal in water based on the properties mentioned above by developing from different lignocellulosic materials and activation agents. Each adsorbent performs different adsorption capacities of FOG depending on many factors, i.e., adsorbent materials, treatment processes, temperature, and FOG concentration. Therefore, in this current work, chemical activation using NaOH, H_3PO_4, and $ZnCl_2$ will be carried out to improve physicochemical properties that are preferable for FOG adsorption.

Table 2.3 Results of adsorption in oil-water emulsions or wastewater reported in the literature

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Adsorbent	Treatment	Material	Pollutant	Adsorption capacity/ Removal percentage	Ref.
Activated carbon	NaOH	*Oleifera moringa* (seeds and pods)	FOG	79 - 87.2 %	(Santos et al., 2020)
Activated carbon	$ZnCl_2$, CO_2	Palm shell	FOG	90%	(Ngarmkam et al., 2011)

Adsorbent	Treatment	Material	Pollutant	Adsorption capacity/ Removal percentage	Ref.
Biochar	-	Rice husk	FOG	2-3 g g^{-1}	(Kandanelli et al., 2018)
Biochar	-	Fruit peels	FOG	57%	(Lam et al., 2018)

2.6 Pyrolysis process

A few years ago, there are three terms (biochar, charcoal, and char), all of which were used in order to indicate the carbonaceous material produced by thermal degradation in oxygen-limited conditions (pyrolysis) of biomasses from plant or animal origin (Bi et al., 2019). Pyrolysis is a thermal decomposition process that involves heat in the absence of oxygen to produce bio-oil, gases, and biochar (Liew et al., 2018). Recently, applications biomass as sorbent precursors is gaining popularity. Through pyrolysis, biomass material has recently been investigated as a promising adsorbent (Derakhshan-Nejad and Jung, 2018; Hu et al., 2019; Ji et al., 2019; Kim et al., 2020). The biomass undergoes a series of chemical reactions mechanism that is highly complicated and partially understood (Tseng, 2006; Wajima, 2017). Dehydration, carboxylation, and aromatization are some of the proposed chemical reactions during the thermochemical conversion of biomass (Tseng, 2006). Dehydration is the water molecule removal from the biomass matrix under thermal

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

conditions. After the biomass moisture decrease, it undergoes elimination of carboxyl groups yielding CO_2. The thermal treatment also affects the formation of aromatic structures. However, it is difficult to maintain steady temperature profiles in pyrolysis reactors; therefore, the reaction mechanisms mentioned above may simultaneously occur (Wajima, 2017).

Under standard pressure conditions in pyrolysis, hemicellulose decomposition occurs between 200-300°C, followed by cellulose decomposing at higher temperatures (300-400°C). Lignin is the most thermochemically stable lignocellulose that decomposes around 600°C (Kambo and Dutta, 2015). During pyrolysis, the reaction pathway is acknowledged to be a free radical process initiated by the homolytic cleavage of bonds around 300°C (Morten Gunnar Grønli, 2002). As the reaction temperature increases (i.e., above 300°C and below 500°C), the tar components formed by the degradation of cellulose mainly consist of anhydrous sugars (anhydrous glucose) that are less reactive than the free radicals produced during bond cleavage. These anhydrous glucose intermediates (tar vapors) and inorganic compounds existing in the biomass volatilize, which later condenses, accounting for the cross-linkage crystal layered and porous char structure. The degradation of polymers (hemicellulose, cellulose, and lignin), the release of volatiles, forming intermediates compounds, and further transformations are all temperature-dependent (Kambo and Dutta, 2015). In an experiment performed on wood species under pyrolysis, the increase in reaction temperature (200-700°C)

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

showed a positive influence on BET surface area (10-500 m^2/g); however, with further increase in reaction temperature (800°C), the surface area was significantly reduced (150 m^2/g) (Schimmelpfennig and Glaser, 2012). The main reason behind the variation in the morphological properties is the volatilization of organic compounds resulting in voids within the biochar matrix. However, high reaction temperature and high heating rates can destroy the fine porous structure, resulting in pores' clogging and reducing the overall surface area (Kloss et al., 2012).

2.7 Interaction of FOG uptake with adsorbent

FOG is the group of organic compounds that has low affinity to water (hydrophobic). This hydrophobic substance adsorption onto adsorbent material with respect to carbonaceous adsorbent; has been demonstrated by the occurrence of **π** interaction between hydrophobic organic compound and the hydrophobic characteristic of the material (Das et al., 2014). The FOG adsorption onto an adsorbent is illustrated on the **Figure 2.3,** as follows.

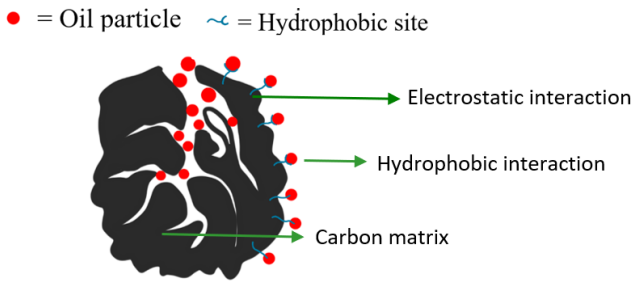


Figure 2.3 Mechanism of FOG adsorption on carbon-based adsorbent (Ahmad et al., 2014)

CHAPTER 3

MATERIALS AND METHODS

3.1 Research materials

3.1.1 Material

1) Rain tree residue

3.1.2 Equipment

1) Soxhlet extractor (Soxtec™ 2050, Denmark)
2) Scanning electron microscope (Hitachi, Japan)
3) Surface area analyzer (Quantachrome, USA)
4) pH meter (Mettler Toledo, USA)
5) ATR-FTIR spectroscopy (Bruker, Germany)
6) Hot air oven (Binder, USA)
7) Shaker (PNP Science, Thailand)
8) Blender (Philips, Thailand)
9) Analytical balance (Mettler Toledo, USA)
10) Water distillers 15 MΩ-cm and 18 MΩ-cm
11) Muffle furnace (Nabertherm, Germany)
12) Sieve

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

13) Vacuum filter

14) Peristaltic pump (Model Master-flex, USA)

15) Column (diameter 3 cm, height 40 cm)

3.1.3 Chemicals

1) Sodium hydroxide (TCI, Japan)

2) Phosphoric acid (TCI, Japan)

3) Zinc chloride (TCI, Japan)

4) Palm oil (Sime Darby Oils Morakot Public Company Ltd.)

5) n-Hexane (Macron, USA)

6) Sulfuric acid (Qrec, New Zealand)

3.2 Experimental procedure

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

3.2.1 Part I: Modified adsorbent production

The rain tree residues were collected from Physical Resources and Management, Chulalongkorn University, Thailand. The collected rain tree residues with 4:1 ratio of leaves and twigs were washed and dried at 105°C in an oven. Then, the biomass was crushed and sieved to get a uniform size (between 0.5 mm - 0.2 mm). The prepared biomass was stored in a sealed polypropylene plastic bag for further use.

For the chemical pretreatments, the crushed biomass was soaked for 120 min in 1M NaOH, 0.3M H_3PO_4, and 0.5M $ZnCl_2$ with ratio biomass: solution (1:5) (w/v). After the pretreatment step, the treated biomass was dried in the oven overnight. Eventually, the treated biomass was ready for a pyrolysis process.

The pyrolysis process was carried out by heating the treated biomass at various temperatures (350, 550, and 750°C) for 2 h after reaching the peak temperature with heating rate 10°C/min in muffle furnace. After cooling, the modified adsorbents were washed with DI water several times until pH ~7 to eliminate residues formed during the process. In the washing step, the modified adsorbents were separated using membrane filters. The modified adsorbents obtained were dried in the oven until completely dry. Thereby, modified adsorbents from rain tree (*Samanea saman)* residue were obtained, kept in tightly sealed plastic, and stored in the desiccator for further analysis. Carbon adsorbent from rain tree (*Samanea saman)* residue without pretreatment was also prepared for control treatment. The scheme of modified adsorbents production is shown in **Figure 3.1** and the yield of modified adsorbent was determined by following equation **(1)**

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

$$\text{Modified adsorbent yield (\%)} = \frac{W_2}{W_1} \times 100 \qquad \textbf{(1)}$$

where, W_1 is dry weight of biomass and W_2 is weight of modified adsorbent.

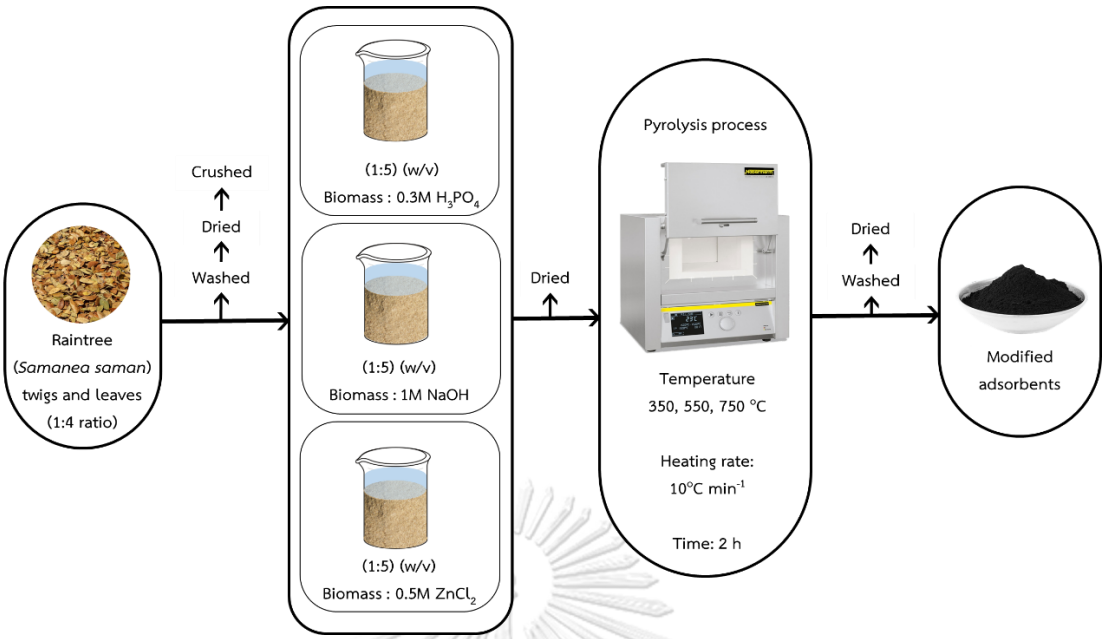


Figure 3.1 Modified adsorbents production scheme

3.2.2 Part II: FOG treatment

Batch sorption test

1) Preliminary adsorption test

A batch sorption screening test was initially conducted to identify the performance of modified adsorbents for FOG removal. Three grams of modified adsorbents were added into 200 mL of 50 mg L^{-1} synthetic emulsified oil wastewater. After shaking for 24 h (1440 min), the supernatant was sampled and analyzed the FOG content. The FOG content was measured by a Soxhlet extraction method (5520D), and a control treatment will be carried out in all adsorption conditions. The best-modified adsorbent was determined using ANOVA and selected for further experiment. All the experiments were run in triplicate to ascertain accuracy.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

The percentage of FOG eliminated was calculated by following equation **(2)**

$$\text{FOG Removal (\%)} = \frac{C_o - C_e}{C_o} \times 100 \quad \textbf{(2)}$$

where C_o and C_e are initial and equilibrium FOG concentrations in mg L^{-1}, respectively. While for the calculation of FOG adsorbed per unit modified adsorbent mass, q_e is obtained from equation **(3)**

$$q_e = \frac{(C_o - C_e)V}{m} \quad \textbf{(3)}$$

where q_e is the FOG amount adsorbed on modified adsorbent (mg g^{-1}), V is the solution volume (L), and m is the modified adsorbent mass (g).

2) Adsorption kinetics

For adsorption kinetic studies, 3 g of best-modified adsorbent from the previous preliminary experiment was added to 200 mL of 100 mg L^{-1} synthetic emulsified oil wastewater. Then, the mixture was shaken for 1440 min (24 h) with 150 rpm at room temperature and sampled periodically at time intervals of 2-1440 min.

Kinetic models were applied for predicting the mechanism of FOG adsorption onto the modified adsorbent. There are two linearized kinetic adsorption models as follows:

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

The pseudo-first-order model in equation **(4)**

$$\ln (q_e - q_t) = \ln q_e - k_1 t \quad \textbf{(4)}$$

where q_e (mg g^{-1}) and q_t (mg g^{-1}) are the adsorption capacities at the equilibrium time and time t, respectively, t (min) is the adsorption time; and k_1 (min^{-1}) is the rate constant for the pseudo-first-order model.

The pseudo-second-order model in equation **(5)**

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \quad \textbf{(5)}$$

where k_2 (g mg^{-1} min^{-1}) is the rate constant for pseudo-second-order model.

3) Adsorption isotherm

For adsorption isotherm studies, 3 g of modified adsorbent was added to 200 mL of varying synthetic emulsified oil wastewater concentrations (10-100 mg L^{-1}) and shaken until the equilibrium time. The adsorption data of the FOG removal was fitted to Langmuir and Freundlich isotherm models as follows:

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

Langmuir model is,

$$\frac{1}{q_e} = \frac{1}{K_L q_m} \cdot \frac{1}{C_e} + \frac{1}{q_m} \quad \textbf{(6)}$$

Freundlich model is,

$$\log q_e = \log K_f + \frac{1}{n} \log C_e \quad \textbf{(7)}$$

where q_m (mg g^{-1}) is the maximum amount of the adsorbed FOG, C_e (mg L^{-1}) is the FOG concentration in the equilibrium, and K_L (L mg^{-1}) is the Langmuir-adsorption constant. K_f (mg g^{-1} (L mg $^{-1})^{1/n}$) is the Freundlich adsorption constant. The scheme of adsorption studies is shown in **Figure 3.2.**

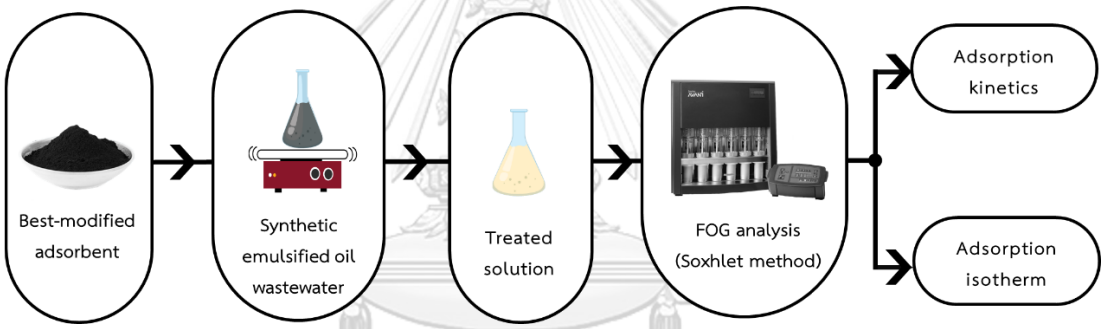


Figure 3.2 Batch sorption experiment scheme

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

FOG analysis

FOG analysis was performed by a Soxhlet extraction method (5520D) (Standard Methods Committee of the American Public Health Association, 2017). The sample was acidified with H_2SO_4 until pH 2 or lower. A filter paper was placed in the Buchner funnel set and connected to the vacuum pump. A 100 mL filter aid suspension was passed through filter paper and washed using DI water. The acidified

sample was filtered and applied vacuum until no more water passes through the filter. The filter paper was entirely transferred into an extraction thimble using forceps. Wiped the Buchner funnel with cotton soaked in n-hexane and placed it along in the extraction thimble. The extraction flask was weighed and added 70 mL n-hexane. The FOG was extracted in a Soxhlet apparatus. Eventually, the extraction flask was cooled before weighing and determining the initial sample volume.

Calculation FOG in a sample as follows:

$$\frac{\text{mg of FOG}}{\text{L}} = \frac{W_r}{V_s} \quad \textbf{(8)}$$

where *Wr* is the total weight of flask and residue minus tare weight of flask (mg) and *Vs* is initial sample volume (L).

Characterization of rain tree (Samanea saman) biomass and best-modified adsorbent

Thermogravimetric analysis of the rain tree *(Samanea saman)* biomass was performed on the Simultaneous TG-DTA Apparatus to identify the mass degradation as increasing temperature. The elemental analysis for biomass and best-modified adsorbent were performed using an element analyzer to analyze C, H, O, N, and S component. The bulk density was determined by the American Society for Testing and Materials (E873-82, 2013). The surface functional groups were characterized by

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Fourier Transform Infra-Red Spectroscopy (FTIR) in the spectral range of 4000-400 cm^{-1}. Scanning electron microscopy (SEM) was applied to characterize the surface morphology of adsorbents. Iodine number and methylene blue number tests were conducted to examine microporosity (pore width > 0–20 Å) and mesoporosity (20–50 Å), respectively. Another surface properties of adsorbents were identified by the N_2-Brunauer-Emmett-Teller (BET) analysis.

Fixed-bed column test

The best-modified adsorbent was continuously examined using a fixed-bed column test to identify the breakthrough times of the column, as shown in **Figure 3.3**. The experiment was conducted using a glass column of 3 cm (diameter) and 40 cm (height). The sampled canteen wastewater was allowed to pass through the bed, packed with best-modified adsorbent. The flow rate was set with a down-flow direction, and outflow was monitored. The output of the column was collected at a regular time.

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

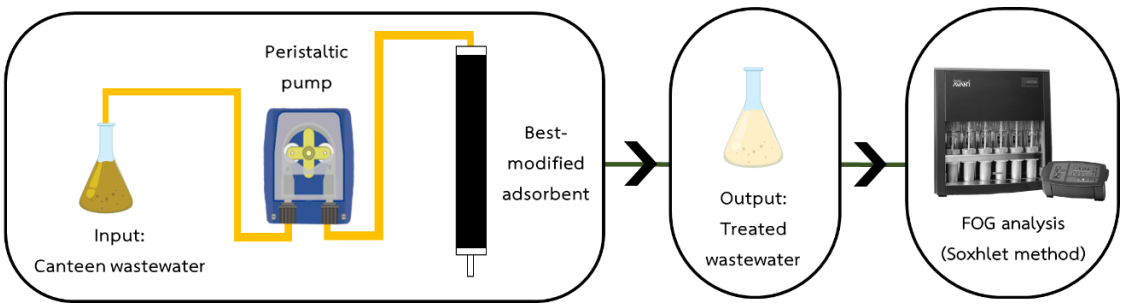


Figure 3.3 Fixed-bed column test scheme

3.2.3 Part III: Technology implementation

In the last part, the best-modified adsorbent among the tested modified adsorbents was selected for economic feasibility analysis. An economic feasibility analysis of the modified adsorbent production from rain tree residues was conducted using equation **(9)** and **(10)**.

The break-even volume (N*):

$$N^* = \frac{FC}{P - V} \quad \textbf{(9)}$$

where N* is the break-even volume, FC is the fixed cost (Baht), P is the price per unit (Baht/Unit), V is the variable cost (Baht).

The payback period:

$$\text{Payback Period} = \frac{N^*}{N} \quad \textbf{(10)}$$

where N* is the break-even volume, N is the productivity (yield/year)

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

CHAPTER 4

RESULT AND DISCUSSION

4.1 Part I: Modified adsorbent production

4.1.1 Modified adsorbent yields and bulk densities

Three types (NaOH, $ZnCl_2$, and H_3PO_4) treated rain tree biomass were produced at the different pyrolysis temperature (i.e., 350, 550, and 750°C). Carbon yield is an important indicator to evaluate the cost of modified adsorbent in large-scale production. **Table 4.1** shows the yield of modified adsorbents obtained from this study are H_3PO_4-treated (38.90±0.16%) – (55.87±1.40%)> $ZnCl_2$-treated (31.99±0.88%) – (48.01±2.26%)> NaOH-treated (14.87±0.51%) – (27.50±1.27%) with decreasing pyrolysis temperature. Some researchers reported similar results, Andas and Wazil (2019) found the maximum activated carbons yield followed an order of H_3PO_4-treated (47.3%)> $ZnCl_2$-treated (45.7%)> KOH-treated (8.4%), when employed mango kernel as the precursor under an production temperature of 500°C. Kılıç et al. (2012) found that the yields of *Euphorbia rigida* activated carbon varied in the range of 29.0–16.8% for H_3PO_4-treated, 29.5–17.8% for $ZnCl_2$-treated, 13.3–9.7% for K_2CO_3-treated, and 13.4–4.1% for NaOH-treated with increasing impregnation of chemical reagent ratio. Briefly, the carbon-based adsorbent yield with an acidic treatment is higher than alkaline and ionic treatment.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Moreover, the result of this study showed that each type modified adsorbent yield decreased with the increasing of temperature. According to the study of Xu et al. (2014) reedy grass leaves showed a weight loss about 72% at 200-400^{o}C in which carbonization process begin and mainly hemicellulose and cellulose fraction decomposition. Therefore, the mass loss is shifted to higher temperatures that contributes to the yield of the modified adsorbent. The temperature influence also depends on the treatment condition process. An excessively high production temperature may decrease the carbon yield and specific surface area. This is because high temperature may lead to excessive transformation of cross-linked substances in the solid phase to volatile matters in the gas phase (Adebisi et al., 2017; Liang et al., 2020).

In this study, the yield of modified adsorbent obtained by H_3PO_4-treated (38.90±0.16%) – (55.87±1.40%) is the highest among other treatments. The carbonization of lignocellulosic component (cellulose, hemicellulose, and lignin) at high temperature decomposes most of the non-carbon elements, mainly hydrogen, oxygen, and nitrogen in the form of liquid (tars) and gases, leaving behind a rigid carbon skeleton in the form of aromatic sheets and strips. The presence of phosphoric acid during process promotes depolymerization, dehydration, and redistribution of constituent biopolymers, and favoring the conversion of aliphatic to aromatic compounds; therefore, increasing the yield of modified adsorbent. Karadirek and Okkay (2018) evaluated influences of H_3PO_4 impregnation ratio, carbonization

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

temperature, and time on activated carbon production. The study found that activated carbon with the maximum carbon yield was obtained at 350 °C, due to the evolution of volatiles and the evaporation of water.

Table 4.1 The yield and bulk density of modified adsorbents

Code	Modified adsorbent type	Temp. (^{0}C)	Initial weight (g)	Final weight (g)	Yield (%)	Bulk density (g mL^{-1})
BAC350	NaOH-treated	350	15.05	4.14	27.50±1.27	0.30
BAC550	NaOH-treated	550	15.05	3.09	20.52±0.22	0.30
BAC750	NaOH-treated	750	15.05	2.24	14.87±0.51	0.26
SAC350	$ZnCl_2$-treated	350	15.05	7.23	48.01±2.26	0.30
SAC550	$ZnCl_2$-treated	550	15.05	6.51	43.22±1.00	0.35
SAC750	$ZnCl_2$-treated	750	15.05	7.94	31.99±0.88	0.35
AAC350	$ZnCl_2$-treated	350	15.05	7.94	55.87±1.40	0.26
AAC550	$ZnCl_2$-treated	550	15.05	6.38	42.38±0.59	0.23
AAC750	$ZnCl_2$-treated	750	15.05	5.86	38.90±0.16	0.30

CHULALONGKORN UNIVERSITY

4.2 Part II: FOG treatment

4.2.1 Preliminary experiment on FOG treatment

Batch sorption experiment

A batch sorption screening test was initially conducted to identify the performance of modified adsorbents for FOG and find the best-modified adsorbent among treatments for further studies. Ten experiments were run in triplicate and

ANOVA was used to assess a significant result of FOG removal compared to control treatment (natural adsorbent). Three grams of each modified adsorbents were added into 200 mL of 50 mg L^{-1} synthetic emulsified oil wastewater. The FOG removal in the synthetic emulsified oil wastewater for all treatments are shown (**Figure 4.1)** with range from (1.35±0.98%) – (93.09±0.97%). However, the ANOVA result of FOG removal (**Table A-3**) indicated that most of the treatments were significantly different (p-value<0.05), and only one treatment (modified adsorbent by NaOH-treated produced at 350°C) was not significantly different (p-value>0.05) from the control treatment (natural adsorbent). These results indicated that most of modified adsorbents performed higher FOG removal compared to the control treatment. In addition, AAC750, which has the highest FOG removal (93.09±0.97%) was not significantly different (p>0.05) with BAC750 (82.78±3.39%), SAC350 (78.45±4.81%), SAC550 (83.66±0.75%), SAC750 (87.62±3.84%), AAC350 (79.77±1.17%), and AAC550 (88.28±4.13%). Therefore, further identification needed to be further conducted to determine the best-modified adsorbent among treatments.

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

Table 4.2 Application of different adsorbents for FOG removal

Adsorbents	Treatment sample	Removal (%)	References
Fruit peels biochar	POME	57	(Lam et al., 2018)
Magnetic palm shell-based activated carbon	POME	80	(Ngarmkam et al., 2011)
Cork-based activated carbon	Sunflower oil-in-water	82	(Pintor et al., 2013)
Saw dust activated carbon	Oil-in-water emulsion	98	(Rajak et al., 2018)
Palm shell activated carbon by physical activation	POME	57	(Ngarmkam et al., 2011)
Palm shell	POME	32	(Ngarmkam et al., 2011)
Modified rice husk	Crude-oil-in-water	49	(Razavi et al., 2015)
Rain tree residue	Synthetic oil wastewater	1.35±0.98	This study
Rain tree residue modified adsorbent	Synthetic oil wastewater	79.77±1.17	This study

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

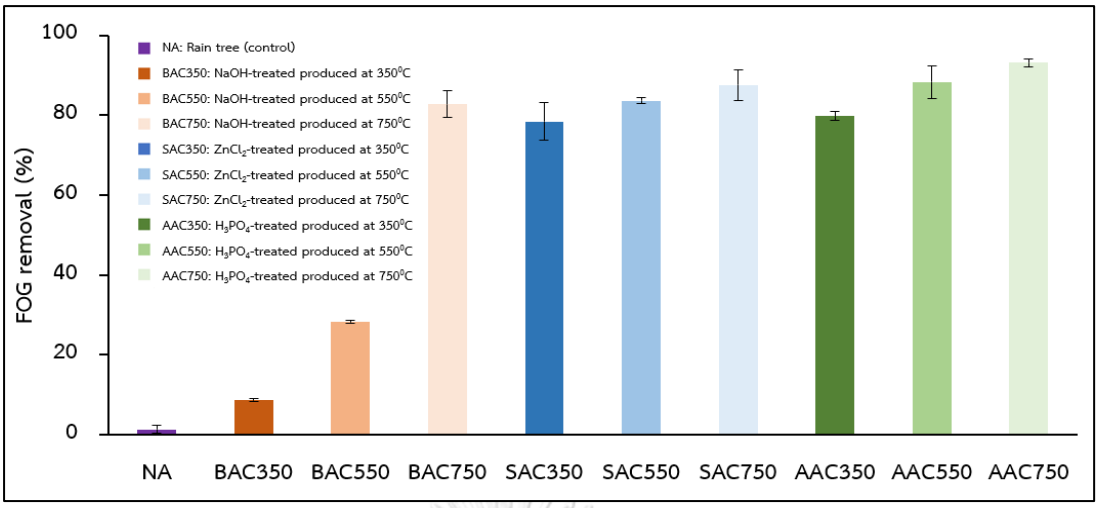


Figure 4.1 FOG removal by different adsorbents (Adsorbent dose 3 g in 200 mL of 50 mg L^{-1} synthetic emulsified oil wastewater, contact time 24 h)

Analysis Zinc (Zn) in the treated synthetic emulsified oil wastewater

As shown in the (**Figure 4.1**), the $ZnCl_2$-treated modified adsorbents are categorized into modified adsorbents that provide high removal for FOG. Due to the involvement of heavy metal (Zn) in $ZnCl_2$ during the modified adsorbent production process, the Zn was analyzed in treated synthetic emulsified oil wastewater to identify the harmful side product after FOG treatment. The residual of Zn after FOG treatment was identified by Atomic Adsorption Spectroscopy (AAS). The result is showed in the **Table 4.3** The residual Zn in the treated synthetic emulsified oil wastewater may be caused by the excess activator agent during impregnation and uncomplete washing process. Therefore, the presence of Zn after FOG treatment

became a consideration for not selecting them as best-modified adsorbent even though it provided high FOG removal with range (78.45±4.80%) – (87.62±3.84%).

Table 4.3 Atomic absorption spectroscopy (AAS) analysis of Zn after FOG treatment using SAC350

Code	Adsorbent type	Concentration (mg L^{-1})
SAC350	$ZnCl_2$-treated	0.7 ± 0.08

Net efficiency of FOG removal

The net efficiency of FOG removal was selected for further identification to define best-modified adsorbent by considering the modified adsorbent yields and removal percentages (**Figure 4.2**). The ANOVA result (**Table A-4**) indicated that most of the treatments were significantly different (*p*-value<0.05), and two treatments using NaOH-treated modified adsorbent were not significantly different (*p*-value>0.05) from the control treatment. However, AAC350 gave the highest net efficiency and had significant difference for FOG removal. The removal and yield percentage are 79.77±1.40% and 55.87±1.17%, respectively.

Accordingly, modified adsorbent by H_3PO_4-treated and produced at 350°C (AAC350) that gave the highest net efficiency of FOG removal was selected as the best-modified adsorbent for further studies.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

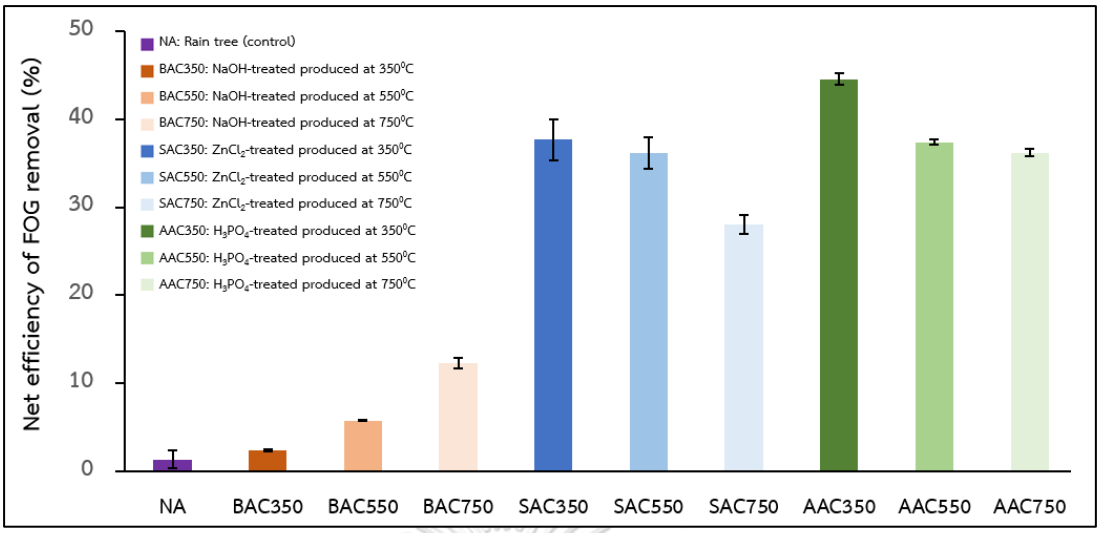


Figure 4.2 Net efficiency of FOG removal by different adsorbents

4.2.2 Characterization of adsorbents

The characterization was performed for the raw material (rain tree residue) and the selected modified adsorbent from previous result (AAC350).

Proximate and ultimate analyzes

A proximate analysis and the ultimate analysis of rain tree residue (twigs and leaves with a ratio of 1:4) and AAC350 are given in **Table 4.5** The proximate analyses of the materials are in terms of moisture content, ash content, volatile matter, and fixed carbon. The fixed carbon content of the materials was calculated by mass difference. From **Table 4.5**, the proximate composition of the raw material was 5.13 wt% moisture, 81.23 wt% volatile matter, 3.99 wt% ash, and 9.65 wt% fixed carbon. While the proximate composition of the prepared modified adsorbent was 4.74 wt% moisture, 66.12 wt% volatile matter, 7.61 wt% ash, and 21.53 wt% fixed carbon. High

volatile matter content usually reduces the solid yield in the carbonization stage while a low inorganic content be able to produce a low ash and high fixed carbon content (Macías-García et al., 2012).

The results of ultimate analysis of rain tree residue and AAC350 show that carbon and oxygen represented the major elements, whereas sulfur, nitrogen, and hydrogen were detected in low concentrations. As shown in **Table 4.4**, different raw material has different elemental component, and the rain tree residue provides comparable element values as raw material for adsorbent. In addition, the low concentration of sulfur in the raw material presents less concern on the production of undesirable sulfur-containing chemicals (e.g., H_2S, SO_2) in the pyrolysis process.

Table 4.4 Elemental component (%wt) of some raw materials for adsorbent.

Raw material	C	H	O	N	S	References
Saw dust	49.62	5.89	44.17	0.21	0.11	(Rajak et al., 2018)
Palm shell	50.01	6.85	-	1.90	-	(Ngarmkam et al., 2011)
Cork	61.90	7.90	29.57	0.63	-	(Pintor et al., 2013)
Banana peel	47.50	6.0	45.5	1.0	0	(Lam et al., 2018)
Orange peel	42.50	6.0	51.0	0.5	0	(Lam et al., 2018)
Rain tree residue	50.64	6.48	41.06	1.76	0.06	This study

An increase in carbon content from rain tree residue to AAC350 (50.64 to 57.02 wt%) has been observed. The hydrogen and oxygen content decreased from 6.48 to 3.17 wt% and 41.06 to 37.36 wt%, respectively. The increase in carbon

content from raw material to modified adsorbent due to an increasing degree of aromaticity (Angin, 2014). The value of the carbon content of the modified adsorbent shows a good agreement with the results reported by Angin (2014) and Fierro et al. (2006).

Table 4.5 Proximate and ultimate analyzes of raw material and AAC350

Analysis	Rain tree residue (%wt)	AAC350 (%wt)
Proximate		
Moisture	5.13	4.74
Volatile	81.23	66.12
Ash content	3.99	7.61
Fixed carbon*	9.65	21.53
Ultimate		
Carbon	50.64	57.02
Hydrogen	6.48	3.17
Nitrogen	1.76	2.45
Sulfur	0.06	0.00
Oxygen*	41.06	37.36

*Calculated by difference.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Thermogravimetry analysis of the precursor (rain tree residue)

TG/DTG study of rain tree biomass was performed to identify the mass degradation as the increase of temperature (**Figure 4.3**). This thermal decomposition of rain tree biomass could be divided into three stages. In the first stage, the amount of moisture is removed during the temperature range of 30-150°C. Due to moisture

loss, the weight was slightly decreased during the initial drying. The second stage, decomposition of hemicellulose, protein, and carbohydrates, occurs from 150°C to approximately 350°C (Araujo et al., 2010). The last stage of the thermal degradation process that characterized the more significant part of mass loss indicated the breakdown of cellulose, lignin, and fatty acid in the sample (starts at 350°C and continues to 500°C).

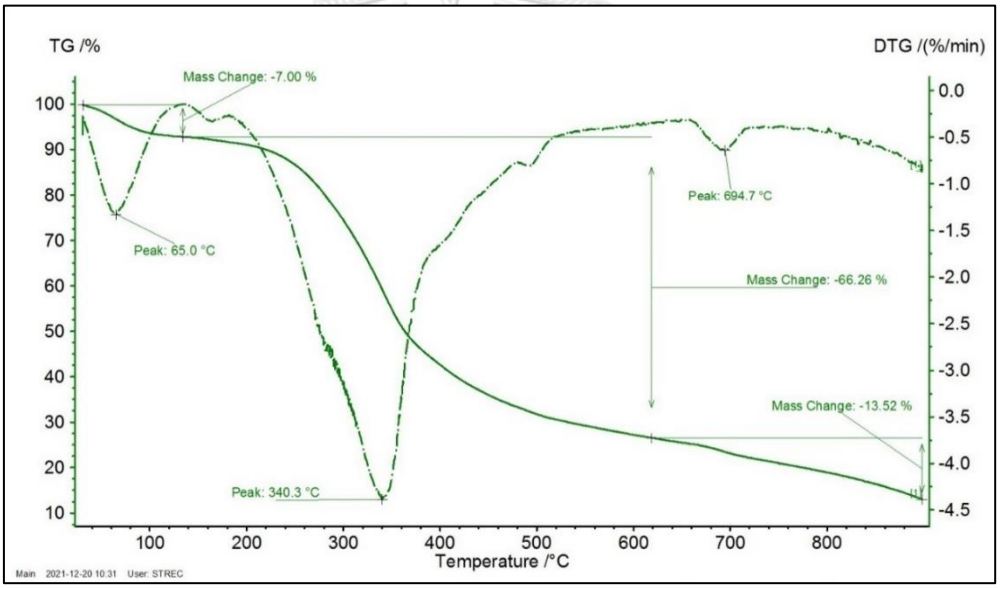


Figure 4.3 TG/DTG Rain tree residue analysis

Surface analysis

The characterization was performed for the modified adsorbent with the best FOG removal in the preliminary experiment. The surface analysis of the best-modified adsorbent, which was prepared by H_3PO_4 treatment and pyrolysis

temperature 350°C (AAC350), was observed by Brunauer-Emmett-Teller (BET) method. The specific surface area value is 8.93 m^2 g^{-1}, which is more significant than its raw material (rain tree residue) 3.11 m^2 g^{-1}. In literature, carbons with much larger surface areas than this study were examined; for example, activated carbon produced from pineapple plant and *Magnolia grandiflora* leaves have a surface area of 1031 m^2 g^{-1} and 41.78 m^2 g^{-1}, respectively (Beltrame et al., 2018; Ji et al., 2019).

Table 4.6 The methylene blue and iodine number analysis result

Adsorbent	Iodine Number (mg g^{-1})	MB Number (mg g^{-1})
Rain tree residue	198.60	2.50
AAC350	88.84	8.07

Moreover, the micropores and mesopores of the adsorbents were carried out by iodine number and methylene blue (MB) tests, respectively. The iodine and methylene blue numbers of rain tree residues adsorbent and AAC350 were shown in **Table 4.6.** The iodine number of AAC350 with 88.84 mg g^{-1} was lower than the rain tree residues adsorbent with 198.60 mg g^{-1}. While the MB number of AAC350 was higher than the rain tree residues with 8.07 mg g^{-1} and 2.50 mg g^{-1}, respectively. The results indicated that the rain tree residues adsorbent mainly consisted of micropores and the AAC350 was consisted of mesopores. The iodine number and MB number of the AAC350 were found to be lower than the commercial activated

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

carbons. It can be caused by the activated carbon preparation that did not meet the optimum conditions to produce good properties of activated carbon. However, rain tree has not been previously investigated as a raw material for generating modified adsorbent. The obtained carbons, therefore, present a potential characteristic for an adsorbent.

Scanning electron microscopy (SEM)

The pores of adsorbents, in turn, can be observed through **Figure 4.4**, which shows the scanning electron microscopy (SEM) results. The SEM of the rain tree biomass and AAC350 shows an uneven surface, presenting pores of different sizes all over it. The images show that the AAC350 is more porous than the rain tree biomass and reconfirmed with the surface area data. **Figure 4.4 (b)** represents that the surface of AAC350 conceives pores generated by the dehydration and activation effect. These pores allow channels for the many molecules to get into a modified adsorbent particle (Islam et al., 2017; Mistar et al., 2020)

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

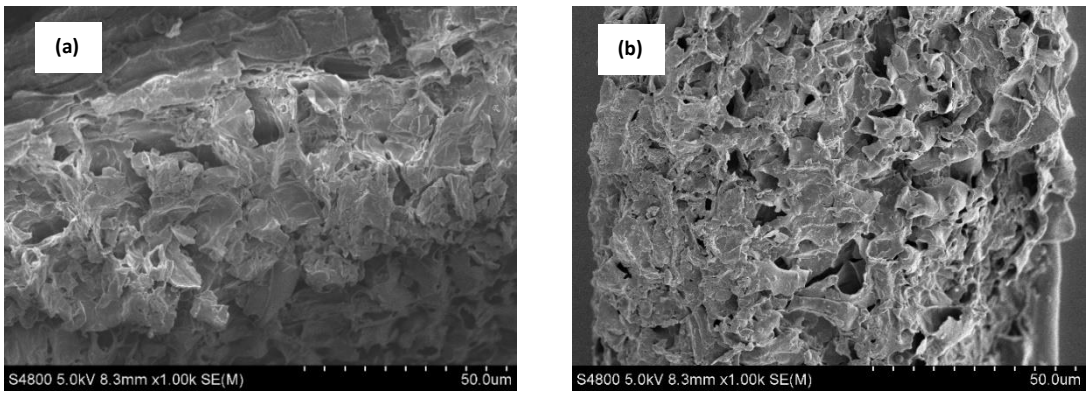


Figure 4.4 SEM images of (a) rain tree biomass (b) AAC350

Fourier transform infrared spectroscopy (FTIR)

The FTIR spectra of rain tree residue modified adsorbent prepared by using H_3PO_4 as activation agent and at temperature 350°C is shown in **Figure 4.5 (A)**, as well as the biomass **(B)** that gave rise to it, as a way of comparison. The result showed that the modified adsorbent spectra exhibited fewer absorption bands and intensity than the biomass, indicating that some functional groups are eliminated after the carbonization and activation processes. The FTIR spectra of the rain tree biomass showed that the broad stretching around 3600-3200 cm^{-1} indicated the presence of hydroxyl (O—H groups) and water. The bands observed around 2800-3000 cm^{-1} occur due to aliphatic (C—H) vibration. The peak observed at about 1637 - and 1031 cm^{-1} indicated the vibration of the carbon double bond (C=C) and phenolic groups, respectively (Santos et al., 2020). Nevertheless, it is also characteristic of phosphorus and phospho-carbonaceous compounds in H_3PO_4 modified adsorbent. The band at 1163 cm^{-1} can be assigned to the vibration of hydrogen-bonded P=OOH groups from phosphates or polyphosphates to the O—C peak in the P—O—C (aromatic) linkage (Puziy et al., 2007; Xu et al., 2014).

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

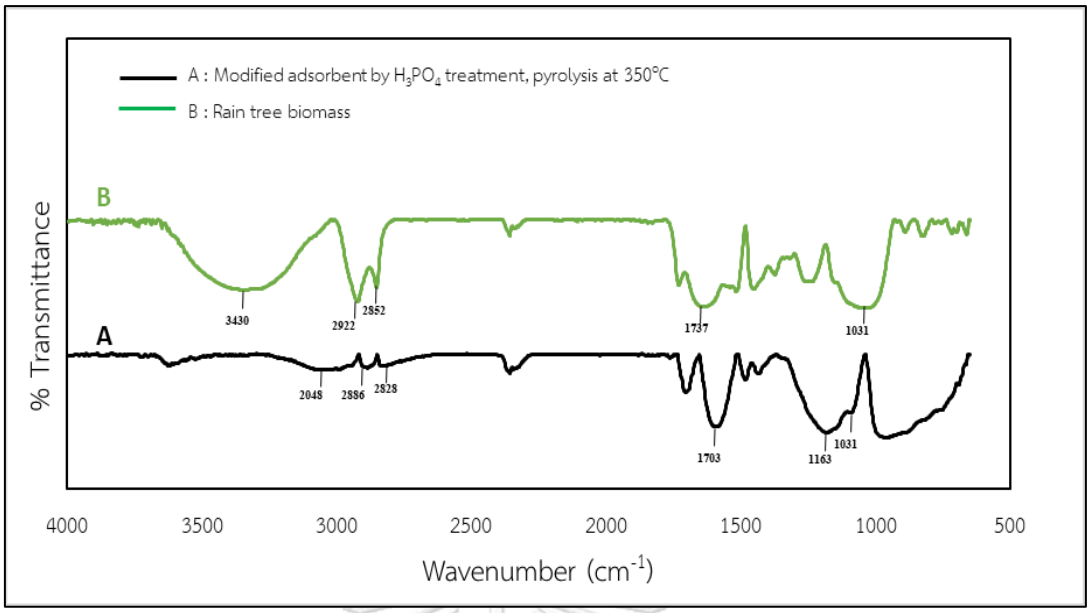


Figure 4.5 FTIR spectrum of the rain tree biomass and AAC350

4.2.3 Adsorption studies of FOG removal

Adsorption kinetic study

Adsorption kinetic experiments were performed to investigate the mechanism of the adsorption. Two adsorption kinetic models were pseudo-first order and pseudo-second order model. The adsorption kinetics were considered to determine the amount of FOG separated from the solution.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

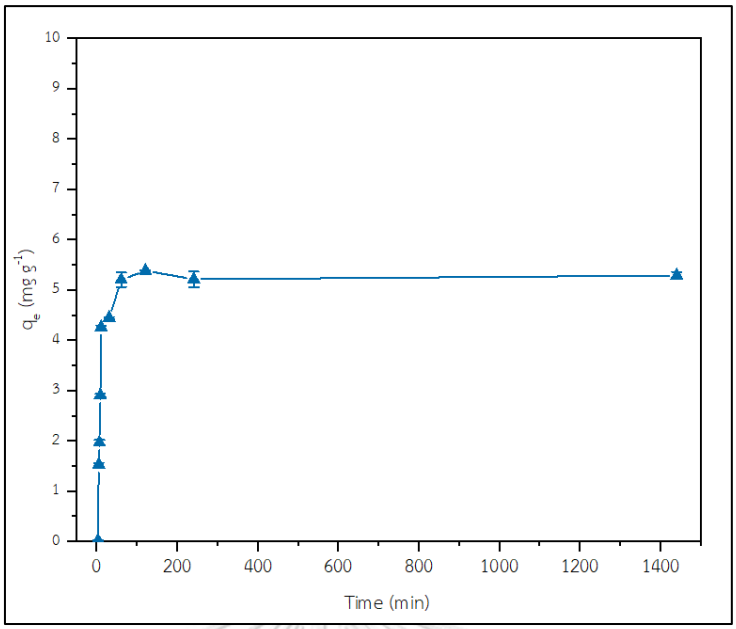


Figure 4.6 Effect of contact time on the adsorption of FOG onto AAC350

Figure 4.6 represents the adsorption of FOG onto AAC350 consists of two phases, the rapid phase, the first 30 min, followed by a relatively slow uptake phase before reaching equilibrium. This initial high rate of FOG adsorption may be attributed to the large number of vacant surface sites being available for adsorption, and as the increasing contact time, less adsorption site on the adsorbent surfaces was available due to the FOG molecules attached to the adsorbent. At a certain point, it reached a constant value which the FOG could not be further removed from the solution. Das and Mishra (2020) observed two stages in the iron adsorption kinetics using activated carbon produced from *Limonia acidissma* shell, a plateau curve reflecting equilibrium. According to Rajak et al. (2018), most oil adsorption equilibrium on synthesized carbon occurred within 3 h. In this current study, adsorption of FOG

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

reached equilibrium in approximately 120 min (2 h), with an equilibrium adsorption capacity (q_e) of 5.39 mg g^{-1}.

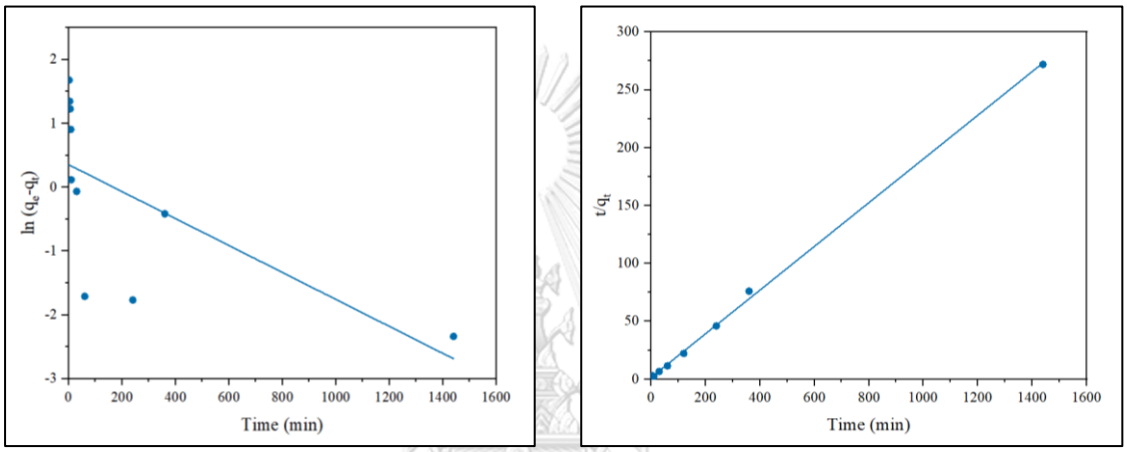
As shown in **Table 4.7**, the adsorption process of FOG onto AAC350 was better described by the pseudo-second-order model with a high correlation coefficient (R^2 = 0.9991) compared to the pseudo-first-order model (R^2=0.4324). Furthermore, the calculated adsorption capacity ($q_{e,\ cal}$) value of 5.29 mg g^{-1} was the same as the experimental adsorption capacity ($q_{e,exp}$) value of 5.29 mg g^{-1}. It is indicated that the adsorption process was controlled by chemisorption, which involved valence forces through the sharing or exchange of electrons between the adsorbent and adsorbate. Literature has shown that oil adsorption is closely related to functional group properties of the sorbent (Said Ael et al., 2009). Refers to the FTIR data (**Figure 4.5**), the AAC350 surface was rich in functional groups. As a result, the surfaces performed well in terms of oil adsorption. Rajak et al. (2018) investigated the adsorption of oil from oil-in-water emulsion using sawdust activated carbon obeyed the pseudo-second-order kinetic rather than pseudo-first-order kinetic model, which is similar to the present work.

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

According to Cai et al. (2019) and Pintor et al. (2013) research results, activated carbon prepared from crab-shell and cork for treating FOG reached 89.4 and 82 mg g^{-1} at equilibrium, respectively, which are much higher than this study. However, rain tree residue as a modified adsorbent precursor for treating FOG has the advantage of low costs, as it can be found ubiquitously.

Table 4.7 Adsorption kinetic models for the adsorption of FOG on AAC350

Pseudo first order			Pseudo second order		
$q_{e,1}$ (mg g^{-1})	k_1 (min^{-1})	R^2	$q_{e,2}$ (mg g^{-1})	k_2 (g mg^{-1} min^{-1})	R^2
1.43	-0.00000146	0.4324	5.29	0.026894189	0.9991



(a) **(b)**

Figure 4.7 (a) Pseudo-first-order model **(b)** Pseudo-second-order model for adsorption of FOG on AAC350

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

Adsorption isotherm study

The adsorption isotherm models provide helpful information to identify the relationship between the amounts of adsorbed by a unit weight of adsorbent and help understand the adsorption mechanism of adsorbate with the adsorbent.

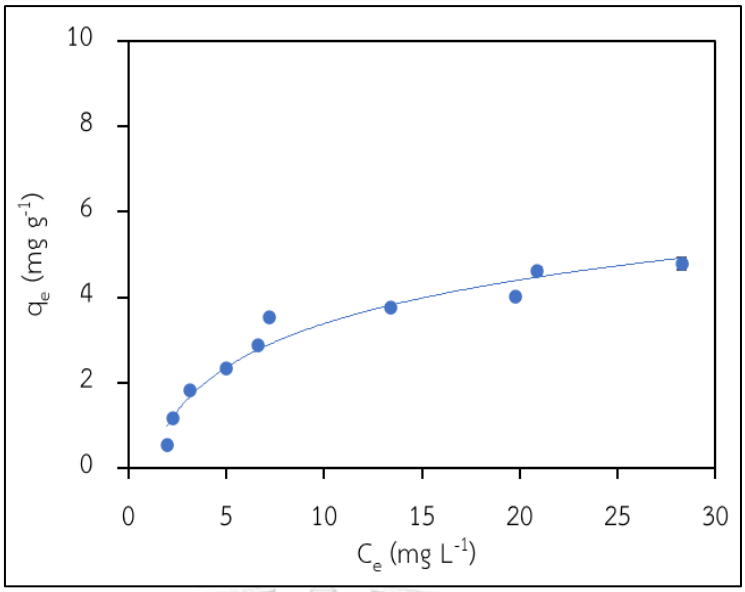


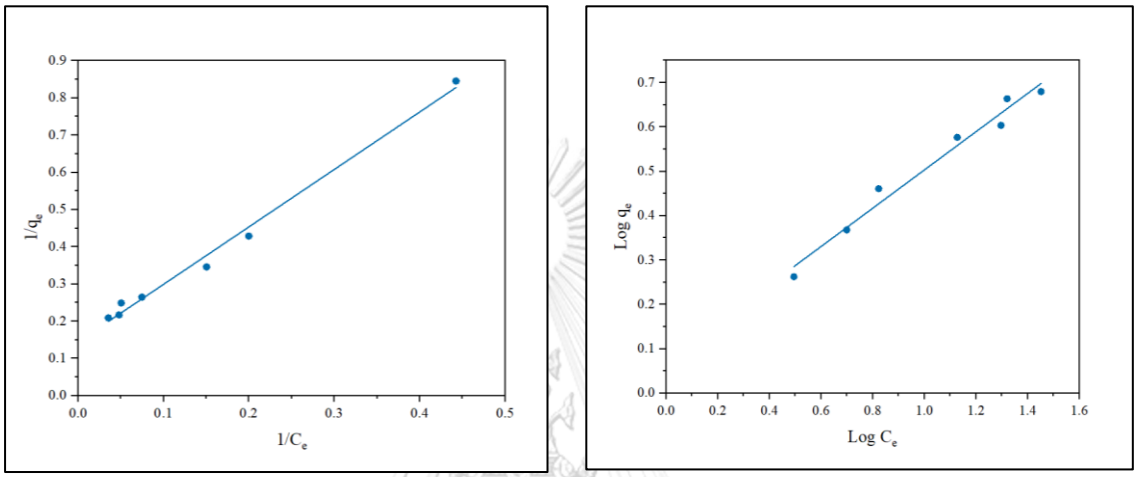
Figure 4.8 Effect of initial concentration on the adsorption of FOG onto AAC350

In this study, Langmuir and Freundlich's isotherms were applied to examine the adsorption behavior of AAC350 for FOG uptake, as shown in **Figure 4.9** (a) and (b). The Langmuir's isotherm assumes monolayer adsorption on homogeneous surfaces. Adsorption occurs without interaction with adsorbed molecules and has similar energy on the surface (without any transmission from adsorbate). The formation of a monolayer adsorbate on the outer surface of the adsorbent obstructs further adsorption, whereas Freundlich's isotherm discusses the type of adsorption on heterogeneous surfaces with interactions between adsorbed molecules (Asep Bayu Dani Nandiyanto, 2020).

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Table 4.8 Adsorption isotherm models for the adsorption of FOG on AAC350

Langmuir				Freundlich		
q_m (mg g^{-1})	K_L (L mg^{-1})	R_L	R^2	n	Kf (mg g^{-1})	R^2
6.8918	0.094	0.60681	0.9911	2.3196	1.1809	0.9755



(a) **(b)**

Figure 4.9 (a) Langmuir adsorption isotherm of FOG on AAC350 (b) Freundlich adsorption isotherm of FOG on AAC350

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

The results presented in **Table 4.8** confirm that Langmuir's isotherm was more suitable with the value of linear regression coefficient (R^2 = 0.9911) than Freundlich's isotherm (R^2 = 0.9755). Hence, the best-fitted isotherm for AAC350 is Langmuir isotherm that the adsorption process of FOG forms a monolayer without any interaction with adsorbed molecules (Wahi et al., 2013). Sohaimi et al. (2017) observed oil adsorption into synthesized biochar and fitted the experimental data into isotherm models. The model also showed that Langmuir model was the most

suitable model for describing the adsorption mechanism of oil adsorption with the highest correlation coefficient (R^2 = 0.9922). Applying Langmuir model, the maximum adsorption capacity was 6.89 mg g^{-1}. The separation factor (R_L) value indicates whether the isotherm was favorable ($0 < R_L < 1$), unfavorable ($R_L > 1$), linear ($R_L = 1$), and irreversible ($R_L = 0$). In this study, R_L of FOG adsorption on the modified adsorbent was calculated 0.6068, which indicated favorable adsorption.

Fixed-bed column experiment

The best modified adsorbent from previous part, AAC350 was filled in a column for examining the FOG removal from canteen wastewater.

1) Canteen wastewater identification

The canteen wastewater was collected from Dormitory canteen, Chulalongkorn University, specifically the wastewater in the collecting tank before the wastewater treatment. The location of wastewater sampling was selected based on the higher activity (opened canteen) compared to other canteens during the COVID-19 situation. Characteristic of the canteen wastewater such as pH, COD, BOD and FOG were determined and compared to the Standard to Control Wastewater Discharge from Certain Types and Sizes of Buildings A.D., (2005). The wastewater parameter results are given in the **Table 4.9**. According to the report from Wastewater Management Team at Chulalongkorn University in 2018, dormitory canteen produced approximately 5.33 m^3 wastewater daily. The FOG content in the

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

influent was detected in high concentration with 90 mg g^{-1}. While in 2022, the FOG concentration in canteen wastewater was found lower with 50 mg g^{-1}. It is because of the campus closure during COVID-19 pandemic affected the quality and quantity of wastewater produced from university's canteen. The sampled dormitory canteen wastewater was used for fixed-bed column test.

Table 4.9 Characterization of dormitory canteen wastewater compared with Type D (area size 100-250 m^2) building effluent standards for food centers in Thailand

Parameters	Unit	Range or Maximum Permitted Value	Dormitory canteen wastewater
pH	-	5-9	6.32
COD	mg L^{-1}	-	2000
BOD	mg L^{-1}	50	1050
FOG	mg L^{-1}	20	50

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

2) Fixed-bed column test

A packed bed experiment was conducted using a glass column of 3 cm diameter and 40 cm height. The bed was supported by glass wool at the top and the bottom bed to avoid bed distribution. A schematic diagram of the fixed packed column is shown in **Figure 4.10**.

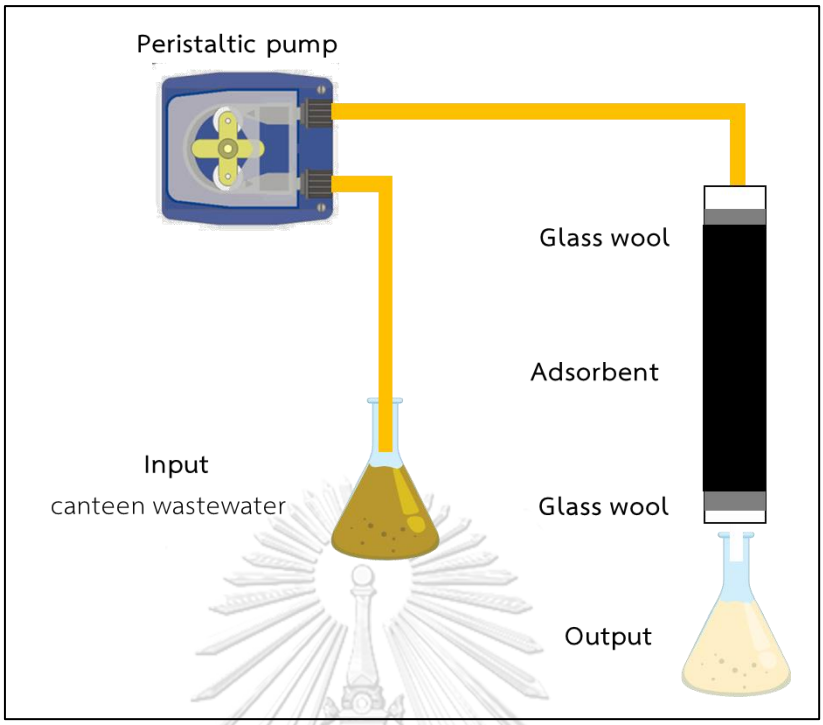


Figure 4.10 Fixed packed column experiment set

In the preliminary experiment, the identified canteen wastewater was allowed to pass through the 400 mm column, which was packed with 100 mm of AAC350, and the wastewater feed flow was set to 5 ml/min. The outlet of the column was collected at an interval time of 400 min and analyzed for the concentration of FOG. The experiment result was shown in **Figure 4.11**. The adsorption of FOG in the packed bed is still not reached a breakthrough point within 400 min with 72.94% removal.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

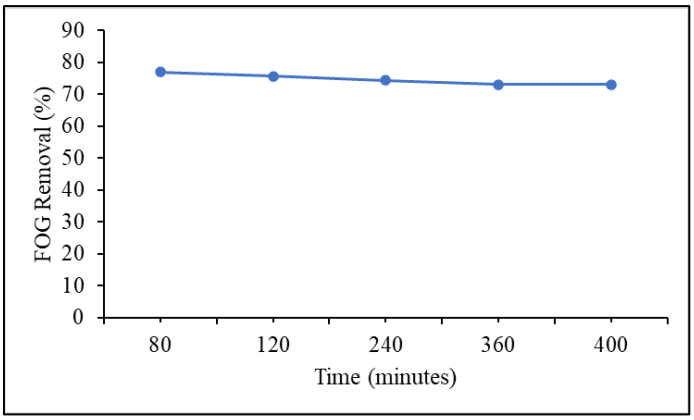


Figure 4.11 The FOG removal in the fixed bed column (Bed height 10 cm, flow rate 5 mL/min, concentration of canteen wastewater 50 mg L^{-1})

According to the previous result, the sampling time was extended to identify the breakthrough point of the FOG removal in the column. The flow rate was adjusted to 10 mL/min. However, the result showed that the column had clogged (**Figure B-5**) within 12 h (720 min) without reaching the breakthrough point by 63.87% removal (shown in **Figure 4.12**).

จุฬาลงกรณ์มหาวิทยาลัย

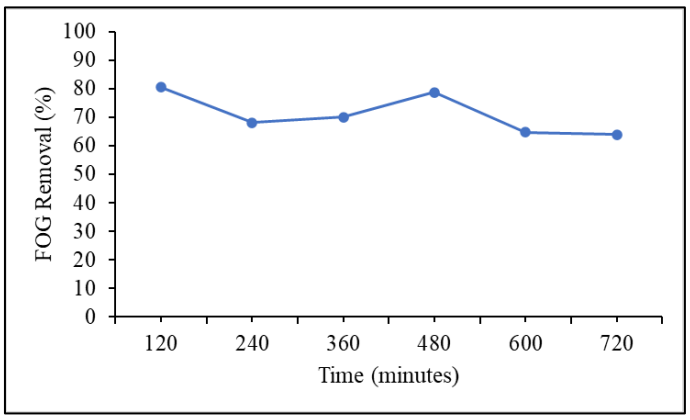


Figure 4.12 The FOG removal in the fixed bed column (Bed height 10 cm, flow rate 10 mL/min, concentration of canteen wastewater 50 mg L^{-1})

Another experiment set was further conducted by adjusting the bed height to 50 mm in order to avoid clogging before it reached breakthrough point. However, the result in **Figure 4.13** describes that the FOG removal in the packed bed reduced as the increasing of time, it is caused by the reducing of available adsorption site on the AAC350. However, the FOG removal was still not reaching a breakthrough point and clogged within 10 h (600 min) with 64.12% removal. This might be caused by the high COD value and the presence of precipitation in the canteen wastewater that might interfere the FOG adsorption in the column. Thus, the fixed bed column experiment provided longer time for FOG removal with 10 cm bed height and 10 mL/min flowrate. In addition, the fixed bed column might be more appropriate for FOG removal in the wastewater with lower COD value and less amount of precipitation.

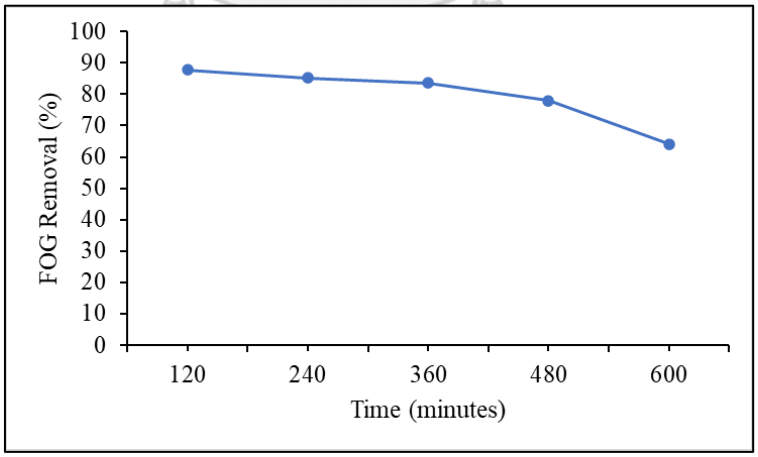


Figure 4.13 The FOG removal in the fixed bed column (Bed height 5 cm, flow rate 10 mL min^{-1}, concentration of canteen wastewater 50 mg L^{-1})

4.3 Part III: Technology implementation

4.3.1 Economic feasibility analysis

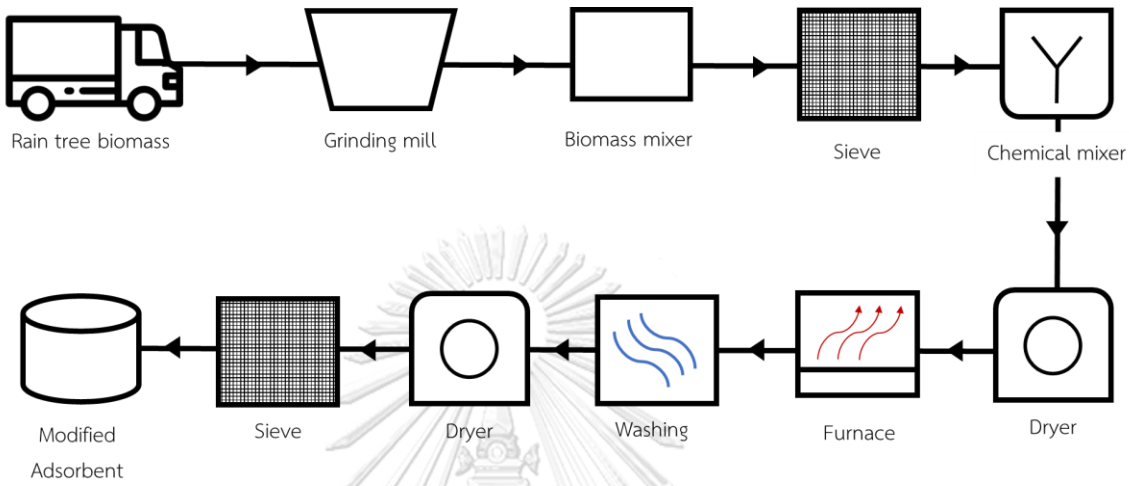


Figure 4.14 Process flow diagram to produce modified adsorbent from rain tree residue

An economic evaluation of AC350 production cost based on the laboratory investigations and experiences were performed and a process flow diagram was established for scale-up (**Figure 4.14)**. Therefore, the cost estimation was conducted based on the underestimated yield of 50% for AAC350 production to ensure feasibility, the number of working days 300 days/year of production, and the estimation of raw material (rain tree residue) loading is 500 kg/day.

Table 4.10 Capacity of machines used for AAC350 production calculations

Machines	Capacity*	Cost	Source
1. Grinding mill	500 kg/h	68,300 Baht/unit	(Eversun Machinery Co., Ltd)
2. Mixer	170 L	13,680 Baht/unit	(S.T. Intertrade, 2022)
3. Hot air oven	1000 L	348,106 Baht/unit	(Thai Furnaces Engineering Co., Ltd)
4. Furnace	1073 L	550,000 Baht/unit	(Thai Furnaces Engineering Co., Ltd)
5. Storage tanks	5000 L	90,000 Baht/unit	(Gencon Engineering Co., Ltd)
6. Sieve machine	500 kg/h	95,600 Baht/unit	(Eversun Machinery Co., Ltd)

* Based on of the machine specification needed.

Table 4.11 Calculation of economic feasibility for AC350 production from rain tree residue biomass

List	Cost	Unit
Fixed Cost (FC)		
1. Grinding mill	68,300	Baht/unit
2. Mixer	13,680	Baht/unit
3. Hot air oven	348,106	Baht/unit
4. Furnace	550,000	Baht/unit
5. Acid storage tanks	90,000	Baht/unit
6. Acid soak tanks	90,000	Baht/unit
7. Acid wash tanks	90,000	Baht/unit
8. Acid recovery tanks	90,000	Baht/unit
9. Sieve machine	95,600	Baht/unit
Total fixed cost (Baht)	**1,435,686**	**Baht**

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Variable cost (V)		
1. Raw material (Baht/kg)		
1.1 AAC350 quantity (underestimating yield by 50%)	250	kg/day
1.2 Raw material demand		
1.2.1 Rain tree residues	500	kg/day
1.2.2 Phosphoric acid (H_3PO_4) 0.3M	110	L/day
1.3 Raw material cost		
1.3.1 Rain tree residues	0	Baht/kg
1.3.2 Phosphoric acid (H_3PO_4) 0.3M	30	Baht/L
Total cost raw material capital/kg	**13.2**	**Baht**
2. Transportation		
Total transportation capital/kg	**0**	**Baht**
3. Variable expense		
3.1 Human labor cost* (2 people)	0	**Baht/day**
3.2 Electricity cost**	18.64	Baht/kg
3.3 Water cost**	0.2	Baht/kg
Total variable expense	**18.84**	**Baht/kg**
Average variable cost (AVC)	**32.04**	**Baht/kg**
Productivity/year (N)		
Working day	300	days/year
Productivity***	250	kg/day
Number (N) (Working day x Productivity)	75,000	kg/year
Price (P)**		
AAC350 cost	36.87	Baht/kg

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

* Human labor cost did not cover on this study due to the labor is Chulalongkorn university staff

** The detail of water and electricity cost was shown in Appendix A

*** Productivity/year was calculated from the production for 500 kilograms AAC350/day

**** The price was determined by increasing 15% the average variable cost (AVC)

The breakeven volume: N* (Kg)

$$N^* = \frac{\text{Fixed Cost}}{\text{Price - Average variable cost}}$$

$$= \frac{1{,}435{,}686}{36.87 - 32.04} = \mathbf{297243.48\ kg}$$

The payback period (Years)

$$\text{Payback period} = \frac{\text{The breakeven volume}}{\text{Productivity/year}}$$

$$= \frac{297243.48}{75{,}000} = \mathbf{3.96\ year}$$

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

According to the cost calculation, average variable cost was 32.04 Baht/kg and the determined price was estimated by increasing 15% of the price (36.87 Baht/kg). The estimated cost of modified adsorbent from rain tree residue was lower than the cost of other adsorbents i.e., activated carbon prepared from iron wood with estimated cost $1.65 per kg (60.11 Baht/kg) (Nowrouzi et al., 2017), acid-treatment adsorbent from pecan shell $2.89 (105.35 Baht/kg) per kg (Ng et al., 2003), and activated carbon prepared from PET wastes $1.7 per kg (61.97 Baht/kg) (Torrik et al., 2014). However, modified adsorbent from rain tree has a lower surface area. As

consequence, modified adsorbent from rain tree residue did not perform significant better quality of adsorbent compared with other commercial adsorbents. However, the laboratory result reported that the modified adsorbent from rain tree residue could be employed for FOG removal in canteen wastewater. The result of economic feasibility identification of rain tree modified adsorbent by H_3PO_4 pretreatment and pyrolysis at 350°C shows that it must produce 297243.48 kg to meet the breakeven volume (N*) which is the point that total cost and total revenue meet equal value. The payback period in which the total cost invested in production can be returned in 3.96 year.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In this study, modified adsorbents were produced from rain tree *(Samanea saman)* to remove FOG. The modified adsorbent by H_3PO_4 pretreatment and pyrolysis at 350°C provided the highest net efficiency of FOG removal, with a yield and removal percentage of 55.87±1.40 and 79.77±1.17%, respectively. The best modified adsorbent was selected for adsorption studies. The data were fitted better to the pseudo-second-order kinetic and Langmuir model. The fixed bed column experiment provided longer time for FOG removal with 10 cm bed height and 10 mL/min flowrate. In addition, the fixed bed column might be more appropriate for FOG removal in the wastewater with lower COD value and less amount of precipitation. Future studies can be carried out to increase this adsorbent's adsorption capacity and remove other pollutants. The results showed that rain tree *(Samanea saman)* could develop adsorbent for FOG removal.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

5.2 Recommendations

5.2.1 The variation of raw material ratio and chemical concentration in pretreatment need to be further examined to find the optimum condition for modified adsorbent from rain tree *(Samanea saman)*.

5.2.2 The management of the used modified adsorbent after treatment can be employed to produce Refuse Derived Fuel (RDF) or concrete.

5.2.3 The fixed-bed column test resulted in good FOG removal, but the column clogging cannot be denied especially for wastewater with high COD and precipitation content. Thus, this process should be combined with other processes such as grease trap before employing the fixed-bed column process.

5.2.4 The application modified adsorbent for COD and BOD treatment can be further examined to identify the other capability of adsorbent.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

REFERENCES

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Abass, O.A. 2011. Application of semifluidized bed bioreactor as novel bioreactor system for the treatment of palm oil mill effluent (POME). African Journal of Biotechnology 10(81).

Acharjee, T.C., Coronella, C.J. and Vasquez, V.R. 2011. Effect of thermal pretreatment on equilibrium moisture content of lignocellulosic biomass. Bioresour. Technol. 102(7), 4849-4854.

Adebisi, G.A., Chowdhury, Z.Z. and Alaba, P.A. 2017. Equilibrium, kinetic, and thermodynamic studies of lead ion and zinc ion adsorption from aqueous solution onto activated carbon prepared from palm oil mill effluent. Journal of Cleaner Production 148, 958-968.

Ahmad, A.L., Sumathi, S. and Hameed, B.H. 2005. Residual oil and suspended solid removal using natural adsorbents chitosan, bentonite and activated carbon: A comparative study. Chem. Eng. J. 108(1-2), 179-185.

Ahmad, M., Rajapaksha, A.U., Lim, J.E., Zhang, M., Bolan, N., Mohan, D., Vithanage, M., Lee, S.S. and Ok, Y.S. 2014. Biochar as a sorbent for contaminant management in soil and water: a review. Chemosphere 99, 19-33.

Andas, J. and Wazil, N. 2019. From Waste Mango Kernel into High Surface Area Activated Carbon. Materials Today: Proceedings 19, 1541-1546.

Angin, D. 2014. Production and characterization of activated carbon from sour cherry stones by zinc chloride. Fuel 115, 804-811.

Araujo, C.S., Alves, V.N., Rezende, H.C., Almeida, I.L., de Assuncao, R.M., Tarley, C.R., Segatelli, M.G. and Coelho, N.M. 2010. Characterization and use of Moringa oleifera seeds as biosorbent for removing metal ions from aqueous effluents. Water Sci. Technol. 62(9), 2198-2203.

Asep Bayu Dani Nandiyanto, G.C.S.G., Rina Maryanti, Risti Ragadhita, Sri Anggraenia, Fajar Miraz Fauzi, Putri Sakinah, Asita Puji Astuti, Dian Usdiyana, Meli Fiandini, Mauseni Wantika Dewi, Abdulkareem Sh. Mahdi Al-Obaidi 2020. Isotherm adsorption characteristics of carbon microparticles prepared from pineapple peel waste. Communications in Science and Technology 5(1), 31–39.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Behera, S., Arora, R., Nandhagopal, N. and Kumar, S. 2014. Importance of chemical pretreatment for bioconversion of lignocellulosic biomass. Renewable and Sustainable Energy Reviews 36, 91-106.

Beltrame, K.K., Cazetta, A.L., de Souza, P.S.C., Spessato, L., Silva, T.L. and Almeida, V.C. 2018. Adsorption of caffeine on mesoporous activated carbon fibers prepared from pineapple plant leaves. Ecotoxicol. Environ. Saf. 147, 64-71.

Bi, Z., Kong, Q., Cao, Y., Sun, G., Su, F., Wei, X., Li, X., Ahmad, A., Xie, L. and Chen, C.-M. 2019. Biomass-derived porous carbon materials with different dimensions for supercapacitor electrodes: a review. Journal of Materials Chemistry A 7(27), 16028-16045.

Boutin, C. and Eme, C. 2016. Domestic Wastewater Characterization by Emission Source. 13eme congres spécialisé IWA on Small Water and wastewater Systems, 8.

Brooksbank, A.M., Latchford, J.W. and Mudge, S.M. 2006. Degradation and modification of fats, oils and grease by commercial microbial supplements. World J. Microbiol. Biotechnol. 23(7), 977-985.

Cai, L., Zhang, Y., Zhou, Y., Zhang, X., Ji, L., Song, W., Zhang, H. and Liu, J. 2019. Effective Adsorption of Diesel Oil by Crab-Shell-Derived Biochar Nanomaterials. Materials (Basel) 12(2).

Castro, J.P., Nobre, J.R.C., Napoli, A., Trugilho, P.F., Tonoli, G.H.D., Wood, D.F. and Bianchi, M.L. 2020. Pretreatment Affects Activated Carbon from Piassava. Polymers (Basel) 12(7).

Chrispim, M.C. and Nolasco, M.A. 2017. Greywater treatment using a moving bed biofilm reactor at a university campus in Brazil. Journal of Cleaner Production 142, 290-296.

Das, R., Abd Hamid, S.B., Ali, M.E., Ismail, A.F., Annuar, M.S.M. and Ramakrishna, S. 2014. Multifunctional carbon nanotubes in water treatment: The present, past and future. Desalination 354, 160-179.

Das, S. and Mishra, S. 2020. Insight into the isotherm modelling, kinetic and thermodynamic exploration of iron adsorption from aqueous media by

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

activated carbon developed from Limonia acidissima shell. Mater. Chem. Phys. 245.

Delgado, D.C., Hera, R., Cairo, J. and Orta, Y. 2016. Samanea saman, a multi-purpose tree with potentialities as alternative feed for animals of productive interest. Cuban Journal of Agricultural Science 48(3).

Denia C. Delgado, R.H., Juan Cairo, Ybett Orta 2016. Samanea saman, a multi-purpose tree with potentialities as alternative feed for animals of productive interest. Cuban Journal of Agricultural Science 48(3).

Derakhshan-Nejad, Z. and Jung, M.C. 2018. Remediation of multi-metal contaminated soil using biochars from rice husk and maple leaves. J. Mater. Cycles Waste Manage. 21(3), 457-468.

E873-82, A.S.f.T.a.M.A. 2013. Standard Test Method for Bulk Density of Densified Particulate Biomass Fuels. (ASTM).

Enniya, I., Rghioui, L. and Jourani, A. 2018. Adsorption of hexavalent chromium in aqueous solution on activated carbon prepared from apple peels. Sustainable Chemistry and Pharmacy 7, 9-16.

Environment, M.o.N.R.a. 2005 WATER QUALITY STANDARDS. Gazette, R.G. (ed).

Evans, L.A.J.T.a.B. 2006. Species Profiles for Pacific Island Agroforestry.

Fierro, V., Torné-Fernández, V. and Celzard, A. 2006. Kraft lignin as a precursor for microporous activated carbons prepared by impregnation with ortho-phosphoric acid: Synthesis and textural characterisation. Microporous Mesoporous Mater. 92(1-3), 243-250.

Gohl, B. (1981) Tropical feeds: feed information summaries and nutritive values.

González-García, P. 2018. Activated carbon from lignocellulosics precursors: A review of the synthesis methods, characterization techniques and applications. Renewable and Sustainable Energy Reviews 82, 1393-1414.

Gratuito, M.K., Panyathanmaporn, T., Chumnanklang, R.A., Sirinuntawittaya, N. and Dutta, A. 2008. Production of activated carbon from coconut shell: optimization using response surface methodology. Bioresour. Technol. 99(11), 4887-4895.

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

Gusain, R., Gupta, K., Joshi, P. and Khatri, O.P. 2019. Adsorptive removal and photocatalytic degradation of organic pollutants using metal oxides and their composites: A comprehensive review. Adv. Colloid Interface Sci. 272, 102009.

Hadoun, H., Sadaoui, Z., Souami, N., Sahel, D. and Toumert, I. 2013. Characterization of mesoporous carbon prepared from date stems by H3PO4 chemical activation. Appl. Surf. Sci. 280, 1-7.

Hu, Y., Zhu, Y., Zhang, Y., Lin, T., Zeng, G., Zhang, S., Wang, Y., He, W., Zhang, M. and Long, H. 2019. An efficient adsorbent: Simultaneous activated and magnetic ZnO doped biochar derived from camphor leaves for ciprofloxacin adsorption. Bioresour. Technol. 288, 121511.

Islam, M.A., Ahmed, M.J., Khanday, W.A., Asif, M. and Hameed, B.H. 2017. Mesoporous activated carbon prepared from NaOH activation of rattan (Lacosperma secundiflorum) hydrochar for methylene blue removal. Ecotoxicol. Environ. Saf. 138, 279-285.

Januszewicz, K., Kazimierski, P., Klein, M., Kardas, D. and Luczak, J. 2020. Activated Carbon Produced by Pyrolysis of Waste Wood and Straw for Potential Wastewater Adsorption. Materials (Basel) 13(9).

Ji, B., Zhu, L., Song, H., Chen, W., Guo, S. and Chen, F. 2019. Adsorption of Methylene Blue onto Novel Biochars Prepared from Magnolia grandiflora Linn Fallen Leaves at Three Pyrolysis Temperatures. Water, Air, & Soil Pollution 230(12).

Kabiri, P., Motaghian, H. and Hosseinpur, A. 2019. Effects of Walnut Leaves Biochars on Lead and Zinc Fractionation and Phytotoxicity in a Naturally Calcareous Highly Contaminated Soil. Water, Air, & Soil Pollution 230(11).

Kamal Al-Malah, M.O.J.A., Nehal I. Abu-Lail 2000. Olive mills effluent (OME) wastewater post-treatment using activated clay. Sep. Purif. Technol. 20, 225–234.

Kambo, H.S. and Dutta, A. 2015. A comparative review of biochar and hydrochar in terms of production, physico-chemical properties and applications. Renewable and Sustainable Energy Reviews 45, 359-378.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Kandanelli, R., Meesala, L., Kumar, J., Raju, C.S.K., Peddy, V.C.R., Gandham, S. and Kumar, P. 2018. Cost effective and practically viable oil spillage mitigation: Comprehensive study with biochar. Mar. Pollut. Bull. 128, 32-40.

Karadirek, Ş. and Okkay, H. 2018. Statistical modeling of activated carbon production from spent mushroom compost. Journal of Industrial and Engineering Chemistry 63, 340-347.

Karcher, M.A., Iqbal, Y., Lewandowski, I. and Senn, T. 2015. Comparing the performance of Miscanthus x giganteus and wheat straw biomass in sulfuric acid based pretreatment. Bioresour. Technol. 180, 360-364.

Kılıç, M., Apaydın-Varol, E. and Pütün, A.E. 2012. Preparation and surface characterization of activated carbons from Euphorbia rigida by chemical activation with $ZnCl_2$, K_2CO_3, NaOH and H_3PO_4. Appl. Surf. Sci. 261, 247-254.

Kim, D. 2018. Physico-Chemical Conversion of Lignocellulose: Inhibitor Effects and Detoxification Strategies: A Mini Review. Molecules 23(2).

Kim, J.E., Bhatia, S.K., Song, H.J., Yoo, E., Jeon, H.J., Yoon, J.Y., Yang, Y., Gurav, R., Yang, Y.H., Kim, H.J. and Choi, Y.K. 2020. Adsorptive removal of tetracycline from aqueous solution by maple leaf-derived biochar. Bioresour. Technol. 306, 123092.

Kloss, S., Zehetner, F., Dellantonio, A., Hamid, R., Ottner, F., Liedtke, V., Schwanninger, M., Gerzabek, M.H. and Soja, G. 2012. Characterization of slow pyrolysis biochars: effects of feedstocks and pyrolysis temperature on biochar properties. J. Environ. Qual. 41(4), 990-1000.

Kumar, M., Upadhyay, S.N. and Mishra, P.K. 2019. A comparative study of thermochemical characteristics of lignocellulosic biomasses. Bioresource Technology Reports 8.

Lam, S.S., Liew, R.K., Cheng, C.K., Rasit, N., Ooi, C.K., Ma, N.L., Ng, J.H., Lam, W.H., Chong, C.T. and Chase, H.A. 2018. Pyrolysis production of fruit peel biochar for potential use in treatment of palm oil mill effluent. J. Environ. Manage. 213, 400-408.

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

Lee, M.E., Park, J.H. and Chung, J.W. 2017. Adsorption of Pb(II) and Cu(II) by Ginkgo-Leaf-Derived Biochar Produced under Various Carbonization Temperatures and Times. Int J Environ Res Public Health 14(12).

Lehmann, J. and Joseph, S. (2012) Biochar for environmental management: science and technology, Routledge.

Lesikar, B.J., Garza, O.A., Persyn, R.A., Kenimer, A.L. and Anderson, M.T. 2006. Food-service establishment wastewater characterization. Water Environ. Res 78(8), 805-809.

Liang, Q., Liu, Y., Chen, M., Ma, L., Yang, B., Li, L. and Liu, Q. 2020. Optimized preparation of activated carbon from coconut shell and municipal sludge. Mater. Chem. Phys. 241.

Liew, R.K., Nam, W.L., Chong, M.Y., Phang, X.Y., Su, M.H., Yek, P.N.Y., Ma, N.L., Cheng, C.K., Chong, C.T. and Lam, S.S. 2018. Oil palm waste: An abundant and promising feedstock for microwave pyrolysis conversion into good quality biochar with potential multi-applications. Process Safety and Environmental Protection 115, 57-69.

Liu, N., Liu, Y., Zeng, G., Gong, J., Tan, X., JunWen, Liu, S., Jiang, L., Li, M. and Yin, Z. 2020. Adsorption of 17beta-estradiol from aqueous solution by raw and direct/pre/post-KOH treated lotus seedpod biochar. J Environ Sci (China) 87, 10-23.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Lloyd, T.A. and Wyman, C.E. 2005. Combined sugar yields for dilute sulfuric acid pretreatment of corn stover followed by enzymatic hydrolysis of the remaining solids. Bioresour. Technol. 96(18), 1967-1977.

Ma, Y. 2016. Comparison of Activated Carbons Prepared from Wheat Straw via ZnCl2 and KOH Activation. Waste and Biomass Valorization 8(3), 549-559.

Maciá-Agulló, J.A., Moore, B.C., Cazorla-Amorós, D. and Linares-Solano, A. 2004. Activation of coal tar pitch carbon fibres: Physical activation vs. chemical activation. Carbon 42(7), 1367-1370.

Macías-García, A., Cuerda-Correa, E.M., Olivares-Marín, M., Díaz-Paralejo, A. and Díaz-Díez, M.Á. 2012. Development and characterization of carbon-honeycomb

monoliths from kenaf natural fibers: A preliminary study. Industrial Crops and Products 35(1), 105-110.

Magnus, K.E. and Seaforth, C.E. 1965. Samanea saman Merrill: the rain tree. A review. Tropical Science 7, 6-11.

Matsumiya, Y., Wakita, D., Kimura, A., Sanpa, S. and Kubo, M. 2007. Isolation and characterization of a lipid-degrading bacterium and its application to lipid-containing wastewater treatment. J Biosci Bioeng 103(4), 325-330.

Menya, E., Olupot, P.W., Storz, H., Lubwama, M. and Kiros, Y. 2018. Characterization and alkaline pretreatment of rice husk varieties in Uganda for potential utilization as precursors in the production of activated carbon and other value-added products. Waste Manag 81, 104-116.

Mian, M.M. and Liu, G. 2020. Activation of peroxymonosulfate by chemically modified sludge biochar for the removal of organic pollutants: Understanding the role of active sites and mechanism. Chem. Eng. J. 392.

Mistar, E.M., Alfatah, T. and Supardan, M.D. 2020. Synthesis and characterization of activated carbon from Bambusa vulgaris striata using two-step KOH activation. Journal of Materials Research and Technology 9(3), 6278-6286.

Mohan, D., Sarswat, A., Ok, Y.S. and Pittman, C.U., Jr. 2014. Organic and inorganic contaminants removal from water with biochar, a renewable, low cost and sustainable adsorbent--a critical review. Bioresour. Technol. 160, 191-202.

Morten Gunnar Grønli, G.V., and Colomba Di Blasi 2002. Thermogravimetric Analysis and Devolatilization Kinetics of Wood. Ind. Eng. Chem. Res. 41, 4201-4208.

Ng, C., Marshall, W.E., Rao, R.M., Bansode, R.R. and Losso, J.N. 2003. Activated carbon from pecan shell: process description and economic analysis. Industrial Crops and Products 17(3), 209-217.

Ngarmkam, W., Sirisathitkul, C. and Phalakornkule, C. 2011. Magnetic composite prepared from palm shell-based carbon and application for recovery of residual oil from POME. J. Environ. Manage. 92(3), 472-479.

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

Nowicki, P., Kazmierczak, J. and Pietrzak, R. 2015. Comparison of physicochemical and sorption properties of activated carbons prepared by physical and chemical activation of cherry stones. Powder Technol. 269, 312-319.

Nowrouzi, M., Younesi, H. and Bahramifar, N. 2017. High efficient carbon dioxide capture onto as-synthesized activated carbon by chemical activation of Persian Ironwood biomass and the economic pre-feasibility study for scale-up. Journal of Cleaner Production 168, 499-509.

Pintor, A.M.A., Silvestre-Albero, A.M., Ferreira, C.I.A., Pereira, J.P.C., Vilar, V.J.P., Botelho, C.M.S., Rodríguez-Reinoso, F. and Boaventura, R.A.R. 2013. Textural and Surface Characterization of Cork-Based Sorbents for the Removal of Oil from Water. Industrial & Engineering Chemistry Research 52(46), 16427-16435.

Pintor, A.M.A., Vilar, V.J.P., Botelho, C.M.S. and Boaventura, R.A.R. 2016. Oil and grease removal from wastewaters: Sorption treatment as an alternative to state-of-the-art technologies. A critical review. Chem. Eng. J. 297, 229-255.

Puziy, A.M., Poddubnaya, O.I., Martínez-Alonso, A., Castro-Muñiz, A., Suárez-García, F. and Tascón, J.M.D. 2007. Oxygen and phosphorus enriched carbons from lignocellulosic material. Carbon 45(10), 1941-1950.

Rajak, V.K., Kumar, S., Thombre, N.V. and Mandal, A. 2018. Synthesis of activated charcoal from saw-dust and characterization for adsorptive separation of oil from oil-in-water emulsion. Chem. Eng. Commun. 205(7), 897-913.

Rashid, R.A., Jawad, A.H., Ishak, M.A.M. and Kasim, N.N. 2016. KOH-activated carbon developed from biomass waste: adsorption equilibrium, kinetic and thermodynamic studies for Methylene blue uptake. Desalination and Water Treatment 57(56), 27226-27236.

Razavi, Z., Mirghaffari, N. and Rezaei, B. 2015. Performance Comparison of Raw and Thermal Modified Rice Husk for Decontamination of Oil Polluted Water. CLEAN - Soil, Air, Water 43(2), 182-190.

Romero-Anaya, A.J., Ouzzine, M., Lillo-Ródenas, M.A. and Linares-Solano, A. 2014. Spherical carbons: Synthesis, characterization and activation processes. Carbon 68, 296-307.

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

Sahota, S., Vijay, V.K., Subbarao, P.M.V., Chandra, R., Ghosh, P., Shah, G., Kapoor, R., Vijay, V., Koutu, V. and Thakur, I.S. 2018. Characterization of leaf waste based biochar for cost effective hydrogen sulphide removal from biogas. Bioresour. Technol. 250, 635-641.

Said Ael, A., Ludwick, A.G. and Aglan, H.A. 2009. Usefulness of raw bagasse for oil absorption: a comparison of raw and acylated bagasse and their components. Bioresour. Technol. 100(7), 2219-2222.

Santos, T.M., de Jesus, F.A., da Silva, G.F. and Pontes, L.A.M. 2020. Synthesis of activated carbon from oleifera moringa for removal of oils and greases from the produced water. Environmental Nanotechnology, Monitoring & Management 14.

Sareena Semae, P.K., Chanvit Vajrabukka, and Somchai Chanpongsang, a.S.P. 2013. Effects of Different Levels of Rain Tree (Samanea saman) Pods in Meal Concentrate on In Vitro Fermentation by a Gas Production Technique. Kasetsart J. (Nat. Sci.) 47, 704-711.

Schimmelpfennig, S. and Glaser, B. 2012. One step forward toward characterization: some important material properties to distinguish biochars. J. Environ. Qual. 41(4), 1001-1013.

Shamsuddin, M.S., Yusoff, N.R.N. and Sulaiman, M.A. 2016. Synthesis and Characterization of Activated Carbon Produced from Kenaf Core Fiber Using H_3PO_4 Activation. Procedia Chemistry 19, 558-565.

Sohaimi, K.S.A. and Ngadi, N. 2016. Removal of Oil Using Activated Carbon from Textile Sludge Biochars. Applied Mechanics and Materials 818, 237-241.

Sohaimi, K.S.A., Ngadi, N., Mat, H., Inuwa, I.M. and Wong, S. 2017. Synthesis, characterization and application of textile sludge biochars for oil removal. Journal of Environmental Chemical Engineering 5(2), 1415-1422.

Standard Methods Committee of the American Public Health Association, A.W.W.A., and Water Environment Federation (2017) Standard Methods for the Examination of Water and Wastewater, American Public Health Association, Washington, DC.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Su, P., Zhang, J., Tang, J. and Zhang, C. 2019. Preparation of nitric acid modified powder activated carbon to remove trace amount of Ni(II) in aqueous solution. Water Sci. Technol. 80(1), 86-97.

Sun, S., Sun, S., Cao, X. and Sun, R. 2016. The role of pretreatment in improving the enzymatic hydrolysis of lignocellulosic materials. Bioresour. Technol. 199, 49-58.

Torrik, E., Nejati, E. and Soleimani, M. 2014. Economic pre-feasibility study for physical conversion of polyethylene terephthalate wastes to activated carbon. Asia-Pacific Journal of Chemical Engineering 9(5), 759-767.

Tseng, R.L. 2006. Mesopore control of high surface area NaOH-activated carbon. J. Colloid Interface Sci. 303(2), 494-502.

Wahi, R., Chuah, L.A., Choong, T.S.Y., Ngaini, Z. and Nourouzi, M.M. 2013. Oil removal from aqueous state by natural fibrous sorbent: An overview. Sep. Purif. Technol. 113, 51-63.

Wajima, T. 2017. A new carbonaceous adsorbent for heavy metal removal from aqueous solution prepared from paper sludge by sulfur-impregnation and pyrolysis. Process Safety and Environmental Protection 112, 342-352.

Xu, J., Chen, L., Qu, H., Jiao, Y., Xie, J. and Xing, G. 2014. Preparation and characterization of activated carbon from reedy grass leaves by chemical activation with H_3PO_4. Appl. Surf. Sci. 320, 674-680.

Yang, L., Li, G., Yang, F., Zhang, S.M., Fan, H.X. and Lv, X.N. 2011. Direct conversion of cellulose to 1-(furan-2-yl)-2-hydroxyethanone in zinc chloride solution under microwave irradiation. Carbohydr. Res. 346(14), 2304-2307.

Yuan, G., Qinyan, Y., Gao, B. and Aimin, L. 2020. Insight into activated carbon from different kinds of chemical activating

agents: A review. Sci. Total Environ. 746, 141094.

Zhang, T., Li, Z., Lü, Y., Liu, Y., Yang, D., Li, Q. and Qiu, F. 2019. Recent progress and future prospects of oil-absorbing materials. Chin. J. Chem. Eng. 27(6), 1282-1295.

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

Zouboulis, A.I. and Avranas, A. 2000. Treatment of oil-in-water emulsions by coagulation and dissolved-air flotation. Colloids and Surfaces 172.

Zu, S., Li, W.Z., Zhang, M., Li, Z., Wang, Z., Jameel, H. and Chang, H.M. 2014. Pretreatment of corn stover for sugar production using dilute hydrochloric acid followed by lime. Bioresour. Technol. 152, 364-370.

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

APPENDIX A

EXPERIMENTAL DATA

Table A-1 FOG removal by different adsorbents (Adsorbent dose 3 g in 200 mL of 50 mg L^{-1} synthetic emulsified oil wastewater, contact time 24 h).

Code	Adsorbent types	Temperature (°C)	Final concentration of FOG (mg L^{-1})	FOG removal (%)
NA	Rain tree (control)	-	49.33	1.35±0.98
BAC350	NaOH-treated	350	45.65	8.70±0.44
BAC550	NaOH-treated	550	10.77	28.19±0.38
BAC750	NaOH-treated	750	10.12	82.78±3.39
SAC350	$ZnCl_2$-treated	350	35.90	78.45±4.81
SAC550	$ZnCl_2$-treated	550	8.17	83.66±0.75
SAC750	$ZnCl_2$-treated	750	5.86	87.62±3.84
AAC350	H_3PO_4-treated	350	8.61	79.77±1.17
AAC550	H_3PO_4-treated	550	6.19	88.28±4.13
AAC750	H_3PO_4-treated	750	3.46	93.09±0.97

Table A-2 Net efficiency of FOG removal by different adsorbents

Code	Adsorbent types	Temperature (°C)	Net removal efficiency (%)
NA	Rain tree (control)	-	1.35±0.98
BAC350	NaOH-treated	350	2.39±0.12
BAC550	NaOH-treated	550	5.78±0.08
BAC750	NaOH-treated	750	12.31±1.09
SAC350	$ZnCl_2$-treated	350	37.67±2.31
SAC550	$ZnCl_2$-treated	550	36.16±0.32
SAC750	$ZnCl_2$-treated	750	28.02±0.57
AAC350	H_3PO_4-treated	350	44.57±0.65
AAC550	H_3PO_4-treated	550	37.41±1.78
AAC750	H_3PO_4-treated	750	36.21±0.38

Chulalongkorn University

Table A-3 ANNOVA analysis result of FOG removal for all treatments

Multiple Comparisons

Dependent Variable: **FOG removal**

Tukey HSD

(I) Adsorbent_types		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
NA	BAC350	-7.35000	4.60719	.836	-23.6645	8.9645
	BAC550	-18.42667*	4.60719	.019	-34.7412	-2.1121
	BAC750	-81.43333*	4.60719	.000	-97.7479	-65.1188
	SAC350	-77.10667*	4.60719	.000	-93.4212	-60.7921
	SAC550	-82.31667*	4.60719	.000	-98.6312	-66.0021
	SAC750	-86.27000*	4.60719	.000	-102.5845	-69.9555
	AAC350	-78.42333*	4.60719	.000	-94.7379	-62.1088
	AAC550	-86.93000*	4.60719	.000	-103.2445	-70.6155
	AAC750	-91.74000*	4.60719	.000	-108.0545	-75.4255
BAC350	NA	7.35000	4.60719	.836	-8.9645	23.6645
	BAC550	-11.07667	4.60719	.373	-27.3912	5.2379
	BAC750	-74.08333*	4.60719	.000	-90.3979	-57.7688
	SAC350	-69.75667*	4.60719	.000	-86.0712	-53.4421
	SAC550	-74.96667*	4.60719	.000	-91.2812	-58.6521
	SAC750	-78.92000*	4.60719	.000	-95.2345	-62.6055
	AAC350	-71.07333*	4.60719	.000	-87.3879	-54.7588
	AAC550	-79.58000*	4.60719	.000	-95.8945	-63.2655
	AAC750	-84.39000*	4.60719	.000	-100.7045	-68.0755
BAC550	NA	18.42667*	4.60719	.019	2.1121	34.7412
	BAC350	11.07667	4.60719	.373	-5.2379	27.3912
	BAC750	-63.00667*	4.60719	.000	-79.3212	-46.6921
	SAC350	-58.68000*	4.60719	.000	-74.9945	-42.3655
	SAC550	-63.89000*	4.60719	.000	-80.2045	-47.5755
	SAC750	-67.84333*	4.60719	.000	-84.1579	-51.5288
	AAC350	-59.99667*	4.60719	.000	-76.3112	-43.6821
	AAC550	-68.50333*	4.60719	.000	-84.8179	-52.1888
	AAC750	-73.31333*	4.60719	.000	-89.6279	-56.9988

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Table A-3 ANNOVA analysis result of FOG removal for all treatments (cont.)

BAC750	NA	81.43333*	4.60719	.000	65.1188	97.7479
	BAC350	74.08333*	4.60719	.000	57.7688	90.3979
	BAC550	63.00667*	4.60719	.000	46.6921	79.3212
	SAC350	4.32667	4.60719	.993	-11.9879	20.6412
	SAC550	-.88333	4.60719	1.000	-17.1979	15.4312
	SAC750	-4.83667	4.60719	.985	-21.1512	11.4779
	AAC350	3.01000	4.60719	1.000	-13.3045	19.3245
	AAC550	-5.49667	4.60719	.965	-21.8112	10.8179
	AAC750	-10.30667	4.60719	.465	-26.6212	6.0079
SAC350	NA	77.10667*	4.60719	.000	60.7921	93.4212
	BAC350	69.75667*	4.60719	.000	53.4421	86.0712
	BAC550	58.68000*	4.60719	.000	42.3655	74.9945
	BAC750	-4.32667	4.60719	.993	-20.6412	11.9879
	SAC550	-5.21000	4.60719	.975	-21.5245	11.1045
	SAC750	-9.16333	4.60719	.615	-25.4779	7.1512
	AAC350	-1.31667	4.60719	1.000	-17.6312	14.9979
	AAC550	-9.82333	4.60719	.528	-26.1379	6.4912
	AAC750	-14.63333	4.60719	.102	-30.9479	1.6812
SAC550	NA	82.31667*	4.60719	.000	66.0021	98.6312
	BAC350	74.96667*	4.60719	.000	58.6521	91.2812
	BAC550	63.89000*	4.60719	.000	47.5755	80.2045
	BAC750	.88333	4.60719	1.000	-15.4312	17.1979
	SAC350	5.21000	4.60719	.975	-11.1045	21.5245
	SAC750	-3.95333	4.60719	.996	-20.2679	12.3612
	AAC350	3.89333	4.60719	.997	-12.4212	20.2079
	AAC550	-4.61333	4.60719	.989	-20.9279	11.7012
	AAC750	-9.42333	4.60719	.581	-25.7379	6.8912
SAC750	NA	86.27000*	4.60719	.000	69.9555	102.5845
	BAC350	78.92000*	4.60719	.000	62.6055	95.2345
	BAC550	67.84333*	4.60719	.000	51.5288	84.1579
	BAC750	4.83667	4.60719	.985	-11.4779	21.1512
	SAC350	9.16333	4.60719	.615	-7.1512	25.4779
	SAC550	3.95333	4.60719	.996	-12.3612	20.2679
	AAC350	7.84667	4.60719	.782	-8.4679	24.1612
	AAC550	-.66000	4.60719	1.000	-16.9745	15.6545
	AAC750	-5.47000	4.60719	.966	-21.7845	10.8445

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Table A-3 ANNOVA analysis result of FOG removal for all treatments (cont.)

AAC350	NA	78.42333*	4.60719	.000	62.1088	94.7379
	BAC350	71.07333*	4.60719	.000	54.7588	87.3879
	BAC550	59.99667*	4.60719	.000	43.6821	76.3112
	BAC750	-3.01000	4.60719	1.000	-19.3245	13.3045
	SAC350	1.31667	4.60719	1.000	-14.9979	17.6312
	SAC550	-3.89333	4.60719	.997	-20.2079	12.4212
	SAC750	-7.84667	4.60719	.782	-24.1612	8.4679
	AAC550	-8.50667	4.60719	.701	-24.8212	7.8079
	AAC750	-13.31667	4.60719	.173	-29.6312	2.9979
AAC550	NA	86.93000*	4.60719	.000	70.6155	103.2445
	BAC350	79.58000*	4.60719	.000	63.2655	95.8945
	BAC550	68.50333*	4.60719	.000	52.1888	84.8179
	BAC750	5.49667	4.60719	.965	-10.8179	21.8112
	SAC350	9.82333	4.60719	.528	-6.4912	26.1379
	SAC550	4.61333	4.60719	.989	-11.7012	20.9279
	SAC750	.66000	4.60719	1.000	-15.6545	16.9745
	AAC350	8.50667	4.60719	.701	-7.8079	24.8212
	AAC750	-4.81000	4.60719	.985	-21.1245	11.5045
AAC750	NA	91.74000*	4.60719	.000	75.4255	108.0545
	BAC350	84.39000*	4.60719	.000	68.0755	100.7045
	BAC550	73.31333*	4.60719	.000	56.9988	89.6279
	BAC750	10.30667	4.60719	.465	-6.0079	26.6212
	SAC350	14.63333	4.60719	.102	-1.6812	30.9479
	SAC550	9.42333	4.60719	.581	-6.8912	25.7379
	SAC750	5.47000	4.60719	.966	-10.8445	21.7845
	AAC350	13.31667	4.60719	.173	-2.9979	29.6312
	AAC550	4.81000	4.60719	.985	-11.5045	21.1245

*. The mean difference is significant at the 0.05 level.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Table A-4 ANNOVA analysis result net efficiency of FOG removal for all treatments

Multiple Comparisons

Dependent Variable: Net efficiency

Tukey HSD

(I) Adsorbent_types		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
NA	BAC350	-1.04333	1.32888	0.998	-5.749	3.6624
	BAC550	-2.71	1.32888	0.584	-7.4157	1.9957
	BAC750	-10.96000*	1.32888	0	-15.6657	-6.2543
	SAC350	-36.32333*	1.32888	0	-41.029	-31.6176
	SAC550	-34.81333*	1.32888	0	-39.519	-30.1076
	SAC750	-26.68000*	1.32888	0	-31.3857	-21.9743
	AAC350	-43.22000*	1.32888	0	-47.9257	-38.5143
	AAC550	-36.07000*	1.32888	0	-40.7757	-31.3643
	AAC750	-34.86333*	1.32888	0	-39.569	-30.1576
BAC350	NA	1.04333	1.32888	0.998	-3.6624	5.749
	BAC550	-1.66667	1.32888	0.953	-6.3724	3.039
	BAC750	-9.91667*	1.32888	0	-14.6224	-5.211
	SAC350	-35.28000*	1.32888	0	-39.9857	-30.5743
	SAC550	-33.77000*	1.32888	0	-38.4757	-29.0643
	SAC750	-25.63667*	1.32888	0	-30.3424	-20.931
	AAC350	-42.17667*	1.32888	0	-46.8824	-37.471
	AAC550	-35.02667*	1.32888	0	-39.7324	-30.321
	AAC750	-33.82000*	1.32888	0	-38.5257	-29.1143
BAC550	NA	2.71	1.32888	0.584	-1.9957	7.4157
	BAC350	1.66667	1.32888	0.953	-3.039	6.3724
	BAC750	-8.25000*	1.32888	0	-12.9557	-3.5443
	SAC350	-33.61333*	1.32888	0	-38.319	-28.9076
	SAC550	-32.10333*	1.32888	0	-36.809	-27.3976
	SAC750	-23.97000*	1.32888	0	-28.6757	-19.2643
	AAC350	-40.51000*	1.32888	0	-45.2157	-35.8043
	AAC550	-33.36000*	1.32888	0	-38.0657	-28.6543
	AAC750	-32.15333*	1.32888	0	-36.859	-27.4476

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Table A-4 ANNOVA analysis result net efficiency of FOG removal for all treatments (cont.)

BAC750	NA	10.96000*	1.32888	0	6.2543	15.6657
	BAC350	9.91667*	1.32888	0	5.211	14.6224
	BAC550	8.25000*	1.32888	0	3.5443	12.9557
	SAC350	-25.36333*	1.32888	0	-30.069	-20.6576
	SAC550	-23.85333*	1.32888	0	-28.559	-19.1476
	SAC750	-15.72000*	1.32888	0	-20.4257	-11.0143
	AAC350	-32.26000*	1.32888	0	-36.9657	-27.5543
	AAC550	-25.11000*	1.32888	0	-29.8157	-20.4043
	AAC750	-23.90333*	1.32888	0	-28.609	-19.1976
SAC350	NA	36.32333*	1.32888	0	31.6176	41.029
	BAC350	35.28000*	1.32888	0	30.5743	39.9857
	BAC550	33.61333*	1.32888	0	28.9076	38.319
	BAC750	25.36333*	1.32888	0	20.6576	30.069
	SAC550	1.51	1.32888	0.974	-3.1957	6.2157
	SAC750	9.64333*	1.32888	0	4.9376	14.349
	AAC350	-6.89667*	1.32888	0.001	-11.6024	-2.191
	AAC550	0.25333	1.32888	1	-4.4524	4.959
	AAC750	1.46	1.32888	0.979	-3.2457	6.1657
SAC550	NA	34.81333*	1.32888	0	30.1076	39.519
	BAC350	33.77000*	1.32888	0	29.0643	38.4757
	BAC550	32.10333*	1.32888	0	27.3976	36.809
	BAC750	23.85333*	1.32888	0	19.1476	28.559
	SAC350	-1.51	1.32888	0.974	-6.2157	3.1957
	SAC750	8.13333*	1.32888	0	3.4276	12.839
	AAC350	-8.40667*	1.32888	0	-13.1124	-3.701
	AAC550	-1.25667	1.32888	0.992	-5.9624	3.449
	AAC750	-0.05	1.32888	1	-4.7557	4.6557
SAC750	NA	26.68000*	1.32888	0	21.9743	31.3857
	BAC350	25.63667*	1.32888	0	20.931	30.3424
	BAC550	23.97000*	1.32888	0	19.2643	28.6757
	BAC750	15.72000*	1.32888	0	11.0143	20.4257
	SAC350	-9.64333*	1.32888	0	-14.349	-4.9376
	SAC550	-8.13333*	1.32888	0	-12.839	-3.4276
	AAC350	-16.54000*	1.32888	0	-21.2457	-11.8343
	AAC550	-9.39000*	1.32888	0	-14.0957	-4.6843
	AAC750	-8.18333*	1.32888	0	-12.889	-3.4776

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Table A-4 ANNOVA analysis result net efficiency of FOG removal for all treatments (cont.)

AAC350	NA	43.22000*	1.32888	0	38.5143	47.9257
	BAC350	42.17667*	1.32888	0	37.471	46.8824
	BAC550	40.51000*	1.32888	0	35.8043	45.2157
	BAC750	32.26000*	1.32888	0	27.5543	36.9657
	SAC350	6.89667*	1.32888	0.001	2.191	11.6024
	SAC550	8.40667*	1.32888	0	3.701	13.1124
	SAC750	16.54000*	1.32888	0	11.8343	21.2457
	AAC550	7.15000*	1.32888	0.001	2.4443	11.8557
	AAC750	8.35667*	1.32888	0	3.651	13.0624
AAC550	NA	36.07000*	1.32888	0	31.3643	40.7757
	BAC350	35.02667*	1.32888	0	30.321	39.7324
	BAC550	33.36000*	1.32888	0	28.6543	38.0657
	BAC750	25.11000*	1.32888	0	20.4043	29.8157
	SAC350	-0.25333	1.32888	1	-4.959	4.4524
	SAC550	1.25667	1.32888	0.992	-3.449	5.9624
	SAC750	9.39000*	1.32888	0	4.6843	14.0957
	AAC350	-7.15000*	1.32888	0.001	-11.8557	-2.4443
	AAC750	1.20667	1.32888	0.994	-3.499	5.9124
AAC750	NA	34.86333*	1.32888	0	30.1576	39.569
	BAC350	33.82000*	1.32888	0	29.1143	38.5257
	BAC550	32.15333*	1.32888	0	27.4476	36.859
	BAC750	23.90333*	1.32888	0	19.1976	28.609
	SAC350	-1.46	1.32888	0.979	-6.1657	3.2457
	SAC550	0.05	1.32888	1	-4.6557	4.7557
	SAC750	8.18333*	1.32888	0	3.4776	12.889
	AAC350	-8.35667*	1.32888	0	-13.0624	-3.651
	AAC550	-1.20667	1.32888	0.994	-5.9124	3.499

*. The mean difference is significant at the 0.05 level.

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Table A-5 The FOG removal in range of time by AAC350 (Adsorbent dose 3 g in 200 mL of 100 mg L^{-1} synthetic emulsified oil wastewater).

Time (min)	Final concentration of FOG (C_o, mg L^{-1})	Adsorption capacity (q_t, mg g^{-1})
2	99.58	0.03±0.01
4	76.97	1.54±0.04
6	70.41	1.97±0.05
8	56.30	2.91±0.03
10	36.01	4.27±0.03
30	33.22	4.45±0.02
60	21.86	5.21±0.14
120	19.14	5.39±0.01
1440	21.71	5.29±0.07

Table A-6 The FOG removal in the variation of initial concentration by AAC350 (Adsorbent dose 3 g in 200 mL of synthetic emulsified oil wastewater).

Initial concentration of FOG (C_o, mg L^{-1})	Final concentration of FOG (C_e, mg L^{-1})	Adsorption capacity (q_e, mg g^{-1})
20	2.26	1.18±0.00
30	3.12	1.68±0.01
40	5.00	2.33±0.03
50	6.65	2.89±0.01
60	7.20	3.52±0.00
70	13.41	3.77±0.04
80	19.81	4.01±0.01
90	20.91	4.61±0.08
100	28.29	4.78±0.15

Table A-7 Adsorption isotherm model fitting of FOG on AAC350.

Initial conc. (C_o, mg L^{-1})	Final conc. (C_e, mg L^{-1})	Adsorption capacity (q_e, mg L^{-1})	Freundlich Isotherm		Langmuir Isotherm	
			$1/C_e$	$1/q_e$	log C_e	log q_e
10	0.53	0.53	0.51	1.87	0.51	1.87
20	2.26	1.18	0.44	0.85	0.44	0.85
30	3.12	1.83	0.32	0.55	0.32	0.55
40	5.00	2.33	0.20	0.43	0.20	0.43
50	6.65	2.89	0.15	0.35	0.15	0.35
60	7.20	3.52	0.14	0.28	0.14	0.28
70	13.41	3.77	0.07	0.27	0.07	0.27
80	19.81	4.01	0.05	0.25	0.05	0.25
90	20.91	4.61	0.05	0.22	0.05	0.22
100	28.29	4.78	0.04	0.21	0.04	0.21

Table A-8 Fixed-bed column of AAC350 (Bed height 10 cm, flow rate 5 mL/min, concentration of canteen wastewater 50 mg L^{-1}).

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

Time (min)	Final concentration of FOG (mg L^{-1})	FOG removal (%)
40	-	-
80	11.54	76.92
120	12.23	75.54
160	-	-
200	-	-
240	12.83	74.33
280	12.23	75.54
320	-	-
360	13.51	72.97
400	13.51	72.97

Table A-9 Fixed-bed column of AAC350 (Bed height 10 cm, flow rate 10 mL/min, concentration of canteen wastewater 50 mg L^{-1}).

Time (min)	Final concentration of FOG (mg L^{-1})	FOG removal (%)
120	9.76	80.47
240	15.95	68.11
360	15.00	70.00
480	10.67	78.67
600	17.67	64.67
720	18.06	63.87

Table A-10 Fixed-bed column of AAC350 (Bed height 5 cm, flow rate 10 mL/min, concentration of canteen wastewater 50 mg L^{-1}).

Time (min)	Final concentration of FOG (mg L^{-1})	FOG removal (%)
120	6.15	87.70
240	7.44	85.11
360	8.23	83.54
480	10.99	78.03
600	17.94	64.12

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

Table A-11 Methylene blue number of NA.

Initial concentration of MB (mg L^{-1})	Final concentration of MB (mg L^{-1})	Adsorption capacity (mg g^{-1})
5	0.45	1.14
10	0.58	2.36
20	0.68	4.83
30	0.90	7.27
40	1.10	9.73
50	1.38	12.15

Table A-12 Methylene blue number of AAC350.

Initial concentration of MB (mg L^{-1})	Final concentration of MB (mg L^{-1})	Adsorption capacity (mg g^{-1})
5	0.10	1.22
10	0.57	2.36
20	2.37	4.41
30	6.39	5.90
40	8.30	7.93
50	12.10	9.48

Table A-13 Iodine number of NA

N_1	N_2	DF	M	S	F	C	X/M
0.1	0.1	2.2	2.835	23.9	50	0.0478	212.3111323
0.1	0.1	2.2	3.3	22	50	0.044	198.4723636
0.1	0.1	2.2	3.766	20.5	50	0.041	185.0360329

Table A-14 Iodine number of AAC350

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

N_1	N_2	DF	M	S	F	C	X/M
0.1	0.1	2.2	2.835	36	50	0.072	93.12677249
0.1	0.1	2.2	3.3	35	50	0.07	88.46636364
0.1	0.1	2.2	3.766	34	50	0.068	84.93457249

Table A-15 Water usage

250 kg AAC350 production		
List	**Amount**	**Unit**
Rain tree residue	**500**	**kg**
Soaking liquid*		
H3PO4 0.3M	**110**	**L**
Water	5,000	L
Washing	5,000	L
Total water needed	**10,000**	**L**

*Biomass: liquid ratio (1:5 w/v)

Table A-16 Water cost calculation

Total water usage	Price/unit	Total electricity cost	Water cost for 1 kg AAC350
10 m^3	10 Baht/m^3	100 Baht	0.2 Baht

Table A-17 Machine specifications

Machines	Value	Unit
Grinding		
Capacity	500	kg/h
Raw material	500	kg
Time usage/day	1	h
Electricity (machine specification)	11	kW
Sieve		
Capacity	500	kg/h
Raw material	500	kg
Time usage/day	1	h
Electricity (machine specification)	12.5	kW

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Table A-17 Machine specifications (cont.)

Mixer		
Capacity	170	L
Raw material	500	kg
Time usage/day	1	h
Electricity (machine specification)	1.2	kW
Furnace		
Capacity	250	kg/h
Raw material	500	kg
Time usage/day	4	h
Electricity (machine specification)	80	kW
Hot air oven		
Capacity	250	kg
Raw material	250	kg
Time usage/day	24	h
Electricity (machine specification)	18	kW

Table A-18 Machine usage

Machine	Time usage	Unit	Power watt	Unit	Electricity usage	Unit
Grinding	1	h	11	kW	11	kWh
Sieve	1	h	12.5	kW	12.5	kWh
Mixer	1	h	1.2	kW	1.2	kWh
Furnace	4	h	80	kW	320	kWh
Hot air oven	24	h	18	kW	432	kWh

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

Table A-19 Electricity cost calculation

Total electricity usage	Price/unit	Total electricity cost	Electricity cost for 1 kg AAC350
776.7 kWh	6 baht/kWh	4660.2 Baht	18.64 Baht

จุฬาลงกรณ์มหาวิทยาลัย
CHULALONGKORN UNIVERSITY

APPENDIX B

PHOTOGRAPHS OF EXPERIMENT

(a) (b) (c)

Figure B-1 Impregnation of rain tree residue in (a) NaOH, (b) $ZnCl_2$, and (c) H_3PO_4

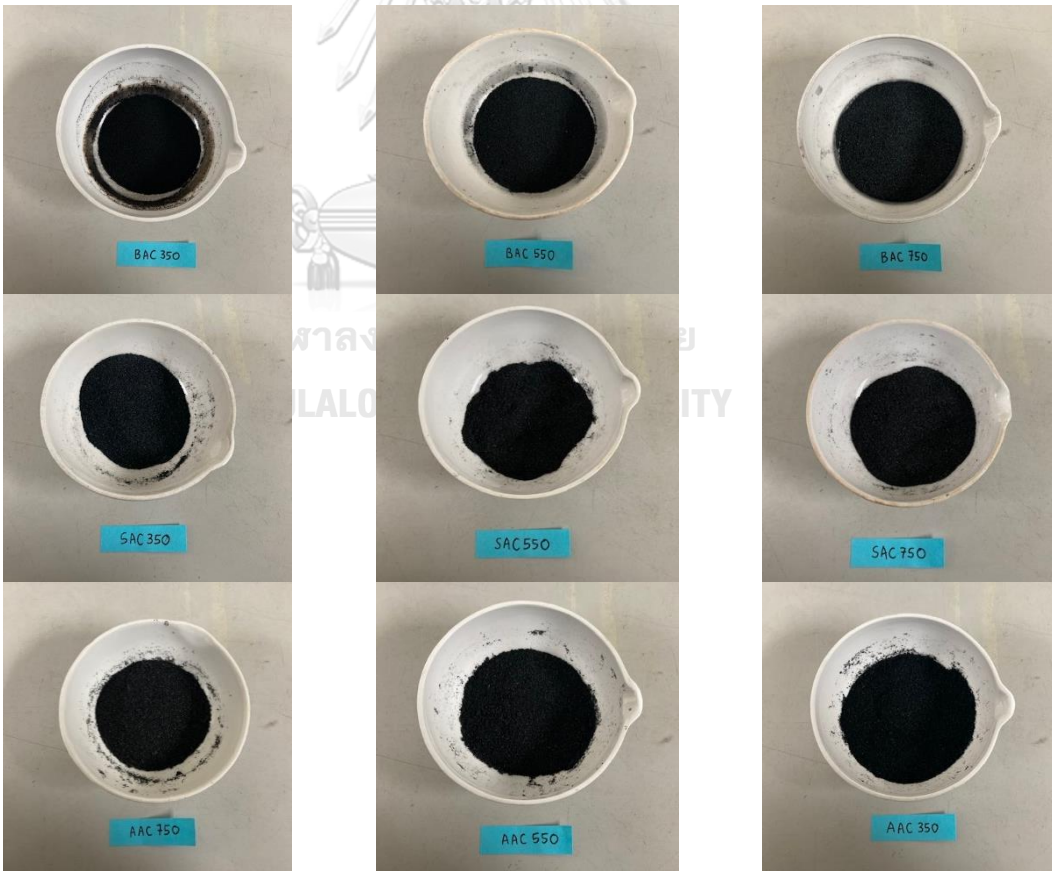


Figure B-2 Modified adsorbents from rain tree residue

Figure B-3 Batch sorption experiment of FOG Removal

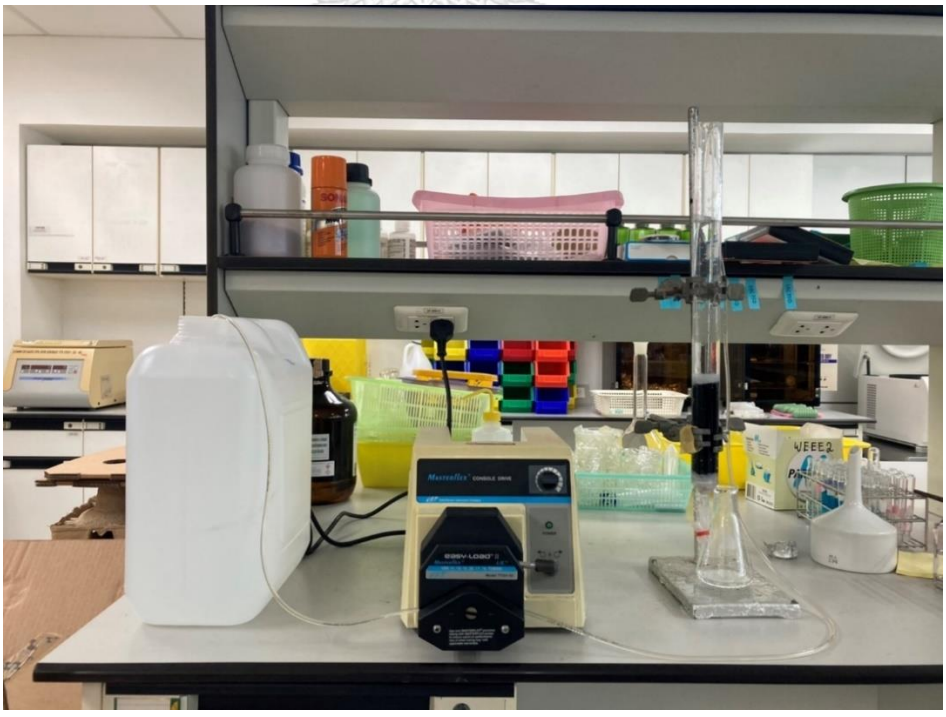


Figure B-4 Fixed bed column experiment of FOG Removal

Figure B-5 Fixed bed column had clogged before reached breakthrough point

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University

VITA

NAME	Elga Riesta Puteri
DATE OF BIRTH	1 August 1995
PLACE OF BIRTH	Sleman, Indonesia
INSTITUTIONS ATTENDED	B.Sc. Chemistry Department, Faculty of Science, Yogyakarta State University, Indonesia
HOME ADDRESS	Banjarsari RT 03/RW 03, Kebondalem Kidul, Prambanan, Klaten, Central Java, Indonesia

จุฬาลงกรณ์มหาวิทยาลัย
Chulalongkorn University