AMPHOTERIC ADSORBENT COATING FOR PHARMACEUTICAL WASTE (DICLOFENAC SODIUM) REMOVAL

MUHAMMAD HAZIQ BIN ABDUL TAIB

UNIVERSITI SAINS MALAYSIA

2021

AMPHOTERIC ADSORBENT COATING FOR PHARMACEUTICAL WASTE (DICLOFENAC SODIUM) REMOVAL

By

MUHAMMAD HAZIQ BIN ABDUL TAIB

Project proposal submitted in partial fulfilment of the requirement for the degree of Bachelor of Chemical Engineering

2021

ACKNOWLEDGEMENTS

The final year project is done for the completion of degree of Bachelor of Chemical Engineering. Multiple supports have been received towards completion of this final year project. Thus, I would like to show my sincerest appreciation and gratitude to all that is involved for their contribution in completion of the project.

Firstly, thank you to Allah SWT for providing me with health, strength, and His blessing and chance for me to complete my final year project. Additionally, I would like to offer my sincere gratitude to my supervisor,

Associate Professor Dr. Suzylawati Ismail for her invaluable guidance, insightful supervision, and endless encouragement throughout this project. Without the guidance and advice from her, this final year project will not be done completely on time. I would also extend my gratitude towards all the postgraduate especially to Syahida Farhan binti Azha for their kindness and cooperation. They are willing to sacrifice their time in providing support and valuable knowledge for me.

Apart from that, I would also like to express my deepest gratitude to my family, fellow friends and course mate for their unending support and encouragement throughout the time. I would also extend my appreciation to all School of Chemical Engineering staffs and USM Library staff for their kind cooperation and commitment in sharing suggestions, expertise, and knowledge for completing my final year report.

Once again, I would like to express my gratitude all the people including my fellow friends as well as those whom I might have overlooked who have aided me directly or indirectly in completion of this project. Thank you very much.

Muhammad Haziq bin Abdul Taib

June 2021

TABLE OF CONTENTS

ACKNOWLEDGEMENTS .... **i**

TABLE OF CONTENTS .... **ii**

LIST OF TABLES .... **iv**

LIST OF FIGURES .... **v**

LIST OF SYMBOLS .... **vi**

LIST OF ABBREVIATION .... **vii**

ABSTRAK .... **viii**

ABSTRACT .... **ix**

CHAPTER 1 INTRODUCTION **1**

1.1 Research Background 1

1.2 Problem Statement 3

1.3 Objectives 4

1.4 Scope of study 4

CHAPTER 2 LITERATURE REVIEW **5**

2.1 Diclofenac properties and environmental impact 5

2.2 Current treatment method 6

2.3 Improvement on current technologies 8

2.4 Treatment Method 9

2.5 Adsorption interaction mechanism 12

2.6 Advanced Wastewater Treatment Plant 13

CHAPTER 3 METHODOLOGY **16**

3.1 Overview of Research methodology 16

3.2 Materials and Chemicals used 18

3.3 Amphoteric Adsorbent Coating formulation 19

3.4 Adsorbent characterization 19

3.5 Batch adsorption study 20

3.5.1 Diclofenac sodium solution preparation 20

3.5.2 Calibration Curve 21

3.5.3 Batch Adsorption Experiment 21

3.6 Comparison with other diclofenac adsorption technique 23

3.7 Thesis and report writing 24

CHAPTER 4 RESULTS AND DISCUSSION 25

4.1 Characterization of the amphoteric absorbent coating 25

4.1.1 Surface morphology 25

4.1.2 Energy dispersion analysis 27

4.2 Adsorption results 29

4.2.1 The effect of EPIDMA dosage of the adsorbents 29

4.2.2 The effect of contact time 30

4.2.3 The effect of diclofenac concentration 31

4.2.4 The effect of solution temperature 33

4.2.5 The effect of pH solution 34

4.3 Adsorption isotherms 35

4.4 Adsorption mechanisms 36

4.5 Comparison with other diclofenac removal technologies 39

4.6 Sustainability 40

CHAPTER 5 CONCLUSION AND RECOMMENDATIONS 42

5.1 Conclusion 42

5.2 Recommendations 43

REFERENCE 44

APPENDICES 51

LIST OF TABLES

Table 2.1 Mean concentration of diclofenac in various stages in Quebec Urban Community wastewater treatment plant 8

Table 2.2 Mean dissolved concentration (ng/L) of diclofenac in inflow and effluent of WWTP and MBR (Clara et al., 2005) 10

Table 2.3 Diclofenac removal efficiency of different advanced WWTP with added tretment technologies 14

Table 3.1 List of chemicals used in the experiment 18

Table 3.2 Properties of Diclofenac sodium 20

Table 3.3 Experimental parameters and its values 22

Table 4.1 Tabulated table of elemental composition analysis of the Energy Dispersion Spectroscopy (EDX) of the AAC strip before adsorption 28

Table 4.2 Tabulated table of elemental composition analysis of the Energy Dispersion Spectroscopy (EDX) of the AAC strip after adsorption 28

Table 4.3 Comparison of adsorption maximum capacities (q_m) of different adsorbents for DCF. 39

LIST OF FIGURES

Figure 2.1 Diclofenac pathway to the environment (Lonappan et al., 2016a) 7

Figure 2.2 Adsorption mechanism UiO-66 for DCF (Hasan et al., 2016) 13

Figure 3.1 Flow diagram of research project on the performance evaluation and determining adsorption capacity of diclofenac removal using AAC. 17

Figure 4.1 SEM images of AAC (a), (b), (c) before adsorption (Mag. 100×, 2000×, 5000× respectively) and (d), (e), (f) after adsorption (Mag. 100×, 2000×, 5000× respectively) 26

Figure 4.2 Energy Dispersion Spectroscopy (EDX) of AAC before adsorption............... 27

Figure 4.3 Energy Dispersion Spectroscopy (EDX) of AAC after adsorption.................. 28

Figure 4.4 Effect of EPIDMA dosage on the removal efficiency of the adsorbent coating for the diclofenac sodium 30

Figure 4.5 Effect of contact time on the removal efficiency of the adsorbent coating for the diclofenac sodium 31

Figure 4.6 Effect of diclofenac solution concentration on the removal efficiency of the adsorbent coating for the diclofenac sodium 32

Figure 4.7 Effect of diclofenac sodium solution concentration on the adsorption capacity of the adsorbent coating for the diclofenac sodium 32

Figure 4.8 Effect of temperature of the diclofenac sodium solution on the removal efficiency of the adsorbent coating for the diclofenac sodium 33

Figure 4.9 Effect of temperature of the diclofenac sodium solution on the adsorption capacity of the adsorbent coating 34

Figure 4.10 Effect of pH of the diclofenac sodium solution on the adsorbent coating for the diclofenac sodium 35

Figure 4.11 Experimental isotherms of the adsorption of DCF using the AAC from aqueous solution 36

Figure 4.12 Adsorption mechanism of AAC towards DCF at pH>pKa............................. 38

Figure 4.13 Adsorption mechanism of AAC towards DCF at pH<pKa............................. 38

LIST OF SYMBOLS

Symbol	Description	Unit
C	Final concentration	mg/L
C_0	Initial concentration	mg/L
C_1	Initial concentration of solution	mg/L
C_2	Final concentration of solution	mg/L
Ce	Concentration at equilibrium	mg/L
$M_{AAC\ strip}$	Mass of the AAC strip	g
$M_{adsorbent}$	Mass of the adsorbent	g
$M_{cotton\ strip}$	Mass of the cotton cloth strip	g
qe	Adsorption capacity	mg/g
V	Volume	L
V_1	Initial volume of solution	L
V_2	Final volume of solution	L
W	Dry weight of the adsorbent	g

LIST OF ABBREVIATION

Symbol	Description
AAC	Amphoteric Adsorbent Coating
AOP	Advance Oxidation Process
APE	Acrylic Polymer Emulsion
COD	Chemical Oxygen Demand
DCF	Diclofenac
EDX	Energy Dispersion Spectroscopy
EPIDMA	Epichlorohydrin-Dimethylamine
GC/MS	Gas Chromatography- Mass Spectrometry
LC-MS/MS	Liquid Chromatography-Mass Spectrometry
NSAID	Non-steroidal Anti-Inflammatory Drugs
SDG	Sustainable Development Goals
SEM	Diclofenac Sodium
UV	Ultraviolet
WWTP	Wastewater Treatment Plant

LAPISAN PENJERAP AMFOTERIK UNTUK PENYINGKIRAN SISA FARMASEUTIKAL (DICLOFENAK NATRIUM)

ABSTRAK

Penyingkiran natrium diclofenak (DCF) menggunakan lapisan penyerap amfoterik unik (AAC) telah dikemukakan oleh tesis ini. Penyerap ini disiapkan sebagai lapisan dan disokong pada kain kapas dengan menggunakan kaedah fasile, berdasarkan penggunaan gabungan serbuk tanah liat berasaskan smektit, emulsi polimer akrilik (APE) dan polielektrolit kationik. Lapisan penyerap dicirikan oleh analisis SEM dan EDX. Eksperimen dilakukan untuk mengkaji pengaruh dos EPIDMA, kepekatan, masa hubungan, suhu, dan pH larutan DCF terhadap kecekapan penyingkiran DCF. Peratusan penyingkiran optimum untuk DCF adalah pada 77.06% pada kepekatan DCF 50 mg/L, suhu 30°C dan pH 3 selama 5 jam. Penjerapan isoterma dikembangkan untuk mengkaji mekanisme penjerapan. Kajian ini menunjukkan bahawa parameter yang disebutkan di atas mempengaruhi prestasi AAC untuk penyingkiran DCF. Dengan kecekapan dan penggunaan semula penyingkiran yang tinggi, AAC didapati sesuai sebagai penyerap yang menjanjikan untuk penyingkiran DCF dari sistem air sisa farmaseutikal.

AMPHOTERIC ADSORBENT COATING FOR PHARMACEUTICAL WASTE (DICLOFENAC SODIUM) REMOVAL

ABSTRACT

The removal of diclofenac sodium (DCF) using a novel amphoteric absorbent coating (AAC) has been presented by this thesis. The formulation of the adsorbent was through a formation of a layer on the surface of a cotton cloth through facile method application using acrylic polymer emulsion (APE), smectite-based clay powder, and cationic polyelectrolyte (EPIDMA). SEM and EDX analysis were conducted for the characterization of the adsorbent coating. The experiments were carried out to study the effect of EPIDMA dosage, concentration, contact time, temperature, and pH of DCF solution on the removal efficiency of the DCF. The optimized percentage removal of DCF is at 77.06% at DCF concentration of 50 mg/L, temperature of 30°C and pH of 3 for 5 hours. Adsorption isotherms were developed to study the adsorption mechanism of the adsorption. This study has shown that the aforementioned parameters influence the performance of the AAC for DCF removal. With high removal efficiency and reusability, AAC was found to be a promising adsorbent for DCF removal from pharmaceutical wastewater system.

CHAPTER 1
INTRODUCTION

1.1 Research Background

Diclofenac (DCF) is a non-steroidal anti-inflammatory drug (NSAID) widely used in the pharmaceutical industry. It is classified as a phenylacetic acid with anti-inflammatory, analgesic, and antipyretic properties. Diclofenac sodium in delayed and extended-release forms were developed to improve the safety profile of diclofenac and provides application conveniency for patients with chronic pains (Altman et al., 2015). It is estimated that the global consumption of diclofenac in the pharmaceutical industries reaches 940 tons annually (Zhang et al., 2008).

Pharmaceutical waste is generally discharged to the environment through sewage treatment plant and improper disposal of expired products, domestic sewage, manufacturing plants waste, hospital waste and runoffs from agricultures (Praveena et al., 2018). The release of the pharmaceutical waste effectively affects the environment as the pharmaceutical residue are released to the water source such as rivers and groundwater system through surface runoff and leaching. Diclofenac undergoes rapid direct photodegradation under natural sunlight (Zhang et al., 2017). Despite that, diclofenac often not removed completely from wastewater treatment plant (WWTP) due to its limited degradation with higher product consumption rates which causes its presence in rivers, sediments sludges and even drinking water sources (Lonappan et al., 2016a). In the recent years, the presence of diclofenac in aquatic environment recorded with concentration at 4900 ng/L in Pakistan (Scheurell et al., 2009) . In Malaysia, the mean diclofenac concentrations were at 4.84 ng/L, 2.76 ng/L and 4.30 ng/L in Gombak, Lui, and Selangor rivers (Praveena et al., 2018). However, higher concentration of up to 188 ng/L were recorded in Langat river due to discharge from sewage treatment plants in Langat River Basin (Al-Odaini et al., 2013).

One study from Hoeger et al., (2005) shows heavy damage to the gills, liver and kidney of brown trout at 50, 000 ng/l. The environmental impact of diclofenac can cause an acute toxic effect to many organisms. From the study (Cleuvers, 2003), diclofenac induced a high mortality rate to crustacea (Daphnia magna sp.) even at acute concentration of mg/l. Normal environmental concentration of diclofenac at 1 ng/l causes chronic adverse effects on fish population.

In a conventional wastewater treatment plant, removal of pollutants occurs in the grit removal unit, primary sedimentation, anaerobic-anoxic-aerobic unit, secondary sedimentation, sand filter unit and UV disinfection unit. Diclofenac is primarily removed through biological treatment in anaerobic tank as degradation is not effective in aerobic tank although some diclofenac is removed in the anoxic tank. The removal efficiency of the wastewater treatment plant ranges from 12% to 65% depending on the removal unit available and the environmental condition such as the seasons (Sari et al., 2014).

Several technologies have been developed in improving the removal of diclofenac in the wastewater plant treatment by using synthetic adsorbent material such as biochar, activated carbon, and silica-based polymer absorbents. Other methods include advance oxidation processes such as ozonation and enzyme utilization for complete degradation of diclofenac from water (Lonappan et al., 2016a)

1.2 Problem Statement

The effluent release from the conventional wastewater treatment plant contains a degradation efficiency of diclofenac with 30-70% removal through activated sludge processes (Vieno and Sillanpää, 2014; Zhang et al., 2008). Improvement have been developed in improving the removal efficiency however drawbacks are produced in the process. Treatment of diclofenac using oxidation process such as ozonation create unwanted and toxic by-products which defeats the purpose of diclofenac removal (Lonappan et al., 2016a). Enzymes could also be used for complete degradation of diclofenac from water without harmful product formation. However, it increases the complexity of the process. Synthetic adsorbent materials could also be use in the removal of diclofenac such as activated carbon which had shown high removal efficiency in a conventional wastewater treatment plant. However, such method requires high budget for the development and operational cost on the removal treatment system. Therefore, higher process energy is expected for system operation.

In Azha et al., (2018a), a novel Amphoteric Absorbent Coating (AAC) have been proposed as a new innovative solution with increases performances and reduction in process energy requirement. The new absorbent coating provides classical adsorption concept with simpler synthesis procedure with amphoteric charge coating that is capable of absorbing both cationic and anionic pollutants such as diclofenac. When dissociates in water, diclofenac forms a negatively charged ions which will interact with positively charged absorbent. The flexible physical characteristics of the AAC provide advantage to be foldable and can be rolled as a flat sheet forming a coating which can be slotted or layered in available limited space in a treatment plant at any condition. The AAC performance in the removal of positive and negatively charged dyes have been studied previously but not diclofenac. Therefore, the performance of the AAC on diclofenac removal are required to find the optimum condition. EPIDMA dosage, initial concentration, contact time and the temperature and pH solution are used as the parameters in evaluating its characteristic and performance. In order to study the characteristics of adsorption of the AAC on diclofenac, adsorption isotherm is determined to predict the adsorption capacities of the adsorbent.

1.3 Objectives

i. To formulate amphoteric absorbent coating for removal of diclofenac sodium.

ii. To evaluate the characteristic and performance of amphoteric adsorbent coating through study effect of EPIDMA dosage, initial diclofenac solution concentration, contact time of the adsorption, solution temperature and solution pH for adsorption of diclofenac sodium removal.

iii. To analyse the adsorption isotherm for the amphoteric adsorbent coating

1.4 Scope of study

The scope of this study is to formulate an amphoteric adsorbent coating (AAC) using a facile in situ intercalative method with mass ratio of acrylic polymer emulsion (APE), bulk clay and poly-epichlorohydrin-dimethylamine (EPIDMA) at 1:2:4 ratio for removal of pharmaceutical waste, diclofenac sodium (DCF). The dosage of the EPIDMA were adjusted to achieved optimal removal efficiency of the coating. The operational conditions of the batch adsorption study will be optimized such as temperature (30 – 75 °C), contact time (0 – 300 min), initial concentration (0 – 50 mg/L), and pH (3 – 11) of the DCF solution. The AAC from the optimized parameters will be characterized using SEM and EDX analysis to study on the physical and chemical properties. The experimental adsorption isotherm will be applied to analyse the equilibrium and the adsorption mechanism.

CHAPTER 2
LITERATURE REVIEW

2.1 Diclofenac properties and environmental impact

Diclofenac is a non-steroidal anti-inflammatory drug (NSAID) which are widely used in as a pain killer which also function as an analgesic for acute injury. It is the most common pain killer administered in the world due to its properties (Lonappan et al., 2016a). The high consumption rate of the pharmaceutical compounds directly corresponds to the increasing pharmaceutical waste generated in the process. Typically, pharmaceuticals that are released to the environment are sourced from sewage treatment plant effluent, industrial plants untreated waste, hospital waste and domestic sewage (Praveena et al., 2018). The pharmaceuticals residue of diclofenac in in surface water bodies in Lui River, Gombak River and Selangor River shows a low potential human health risk with HQ_{HH} values of less than 1. However, the ecotoxicological risk shows high risk with respiratory quotient (RQ) of greater than 30 (Praveena et al., 2018). This shows that diclofenac can still cause serious environmental impact if it is discharges to main water source without being regulated.

The study conducted by Sathishkumar et al., (2020) on the toxicity of diclofenac in animals, birds, and plants has been shown to cause significant effect. Vultures' population have shown severely impacted in India, Bangladesh, Pakistan and Nepal through consumption of diclofenac-medicated animals with exposure level of 0.8 mg/kg. The diclofenac causes nephrotoxicity on the vulture by accumulation of uric acid crystal in the visceral organs. Nephrotoxic, cardiotoxic, hepatoxic, hemotoxic, genotoxic, and neurotoxic effects have been caused by diclofenac in mammals affecting their organs, tissue functions and growth stages with exposure level from 1.1 mg/kg to 100 mg/kg with higher exposure causing higher severity. Chronic exposure of diclofenac in aquatic animal at low doses are well recognized due to their direct contact in aquatic environment. Due to their longer exposure duration with diclofenac, low exposure amount could still cause major health effect to the aquatic animals as low as 0.03 μg/ L exhibit in European carp. Plant is also affected by exposure to the diclofenac which can cause cytotoxic and genotoxic effects in plants at 0.3 μg/ L. Irrefutably, exposure to diclofenac causes adverse effect on organisms including birds, aquatic animals, fish, and plants with long-term exposure causes a more severe effect on the animals. Globally, diclofenac was detected at a concentration from ng to μg levels accumulated on water surface, soil, and plants. Thus, action is needed in reducing the release of diclofenac to the environment to a safe level.

2.2 Current treatment method

Diclofenac that are released from the pharmaceutical industries are typically treated in a conventional wastewater treatment plant with excess and expired products being dumped into a landfills as shown in **Figure 2.1** (Lonappan et al., 2016a). Conventional wastewater treatment plant (WWTP) plays a major role toward reducing the discharge of diclofenac to the environment as the excess and expired diclofenac sourced from human medication consumption and veterinary medicine that are disposed to landfills are harder to control.

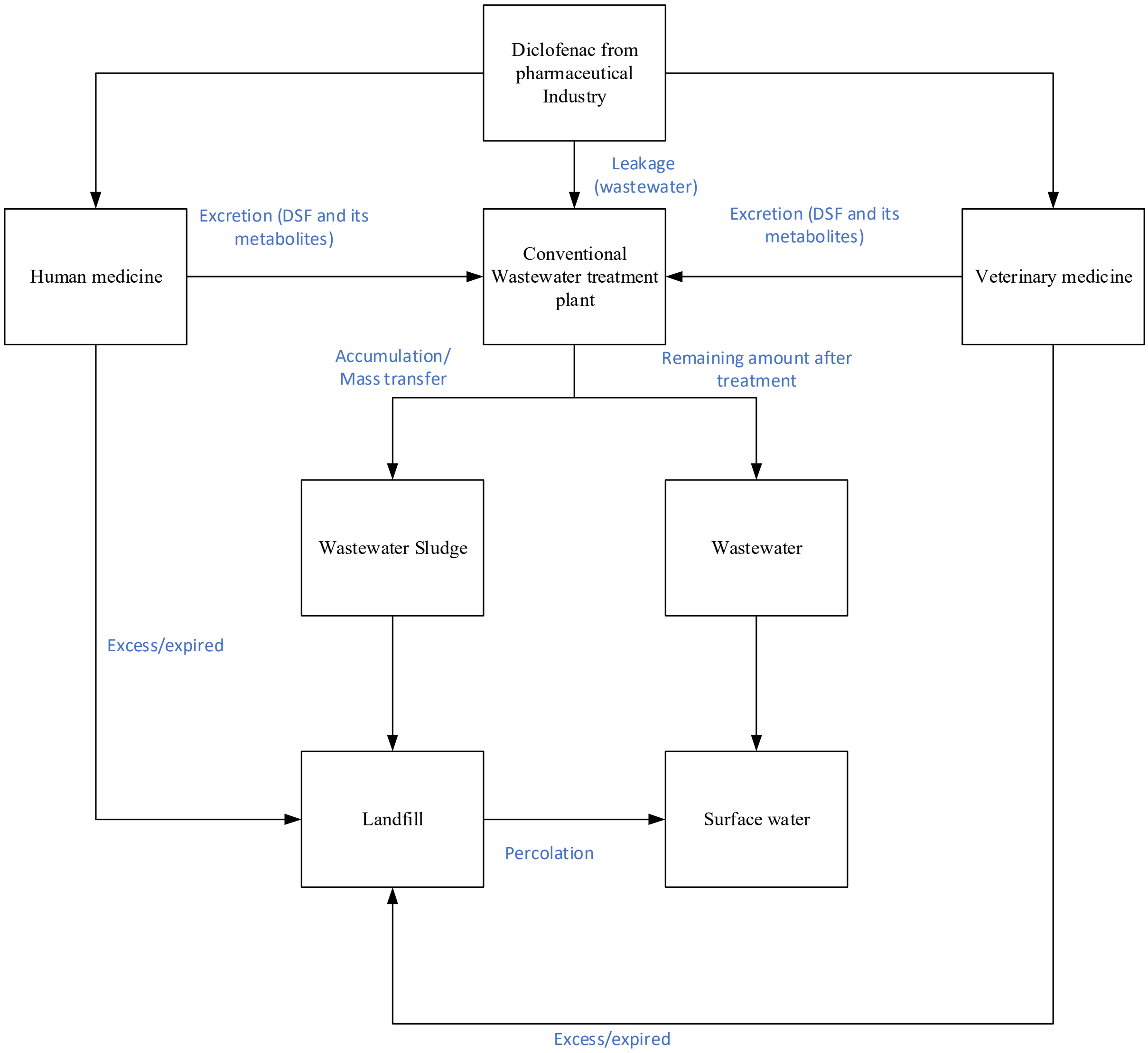


Figure 2.1 Diclofenac pathway to the environment (Lonappan et al., 2016a)

In a wastewater treatment plant, the presence of diclofenac at various stages in the processes are shown in **Table 2.1**. The wastewater treatment plant are based on Quebec Urban Community WWTP which received wastewater from several hospitals in the area of the Quebec City (Lonappan et al., 2016b). The detected concentration in the influent of the wastewater treatment plant was 64.89 µg/L while the effluent of the treatment plant contains 15.95 µg/L. the removal efficiency of the conventional wastewater treatment plant are at about 75% which is considered to be within the range similarly reported in Vieno and Sillanpää, (2014). The maximum discharge of diclofenac varied from one another as municipal wastewater varies between 0.44 and 7.1 µg/L with mean concentration oof 0.11 and 2.3 µg/L.

Reported values of diclofenac shows higher concentration at 6.88 μg/L from hospital wastewater and 203 μg/L in pharmaceutical industries' wastewater in South Korea (Vieno and Sillanpää, 2014). Due to its incomplete elimination in the treatment process, effluent concentration from the wastewater treatment plant hardly falls below the detection limit of ng/L level of LC–MS/MS or GC/MS. The maximum concentration of diclofenac in the effluent from the wastewater treatment plant reported at 0.12 and 4.7 μg/L with mean concentration of less than 0.002 and 2.5 μg/L.

Table 2.1 Mean concentration of diclofenac in various stages in Quebec Urban Community wastewater treatment plant

WWTP Stages	**Diclofenac concentration (μg/L)**
Pump	64.89 ± 6.7%
Grease & grit removal	52.75 ± 4.7%
Primary clarifier	34.91 ± 2.8%
Primary clarifier Sludge liquid	5.85 ± 17.9%
Primary clarifier sludge solid	0.53 ± 17.3%
Secondary clarifier	24.48 ± 12.2%
Secondary clarifier Sludge liquid	1.97 ± 20%
Secondary clarifier sludge solid	0.65 ± 14.4%
UV disinfection	15.95 ± 3.7%

2.3 Improvement on current technologies

Despite the current removal efficiency of the conventional treatment plant, improvement is required to compensate on the harmful diclofenac concentration from the effluent discharge to the environment. Diclofenac removal from wastewater require an efficient removal at low concentration occur at a time range from minutes to days due to the short retention time in a treatment plant. Effective removal of the pollutants requires a high selective and rapid reactions such as advanced oxidation processes (AOPs) that combines reactive oxidants including ultrasound oxidation, photocatalysis and ozonation or adsorbents material such as activated carbon (Langenhoff et al., 2013)

2.4 Treatment Method

Advanced oxidation process (AOP) can be characterized from the production of a highly reactive and unselective species such a hydroxyl radical which are able to undergo degradation on recalcitrant molecules into a biodegradable compounds intermediate compound or even a completely mineralize into carbon dioxide, water, and inorganic ions (Langenhoff et al., 2013). However, the degradation process may also result into the formation of potentially harmful by-products due to the application of the oxidation technologies by a large ecological footprint from its high energy demand (Schwarzenbach et al., 2006). A study conducted by Rosales et al., (2019) shows reduction of diclofenac of up to 97% in only 10 mins with the pH solution maintained at 3.21. It can be noted that the studied are conducted in a small scale with concentration of 10 μL of diclofenac. However, a higher degradation rate can be achieved at higher current in the process as the experiment are conducted at 300 mA of current. Similar result has been obtained by other studies with up to 100% removal efficiency (Yu et al., 2013). It is also noted that in the process, the toxicity of the degradation products and intermediate products suggested that the use of advanced reduction process is more suitable in removing the toxicity. However, a higher irradiation dose is required in the process.

Biological techniques have also been used to remove pharmaceutical waste such as ibuprofen and diclofenac. Biological techniques are considered more vigorous with lesser cost in removing micropollutants compared to oxidation process. However, micropollutants are not able to sufficiently be removed due to the currently operated high organic loaded biological water treatment systems which focus on chemical oxygen demand (COD) and nutrient removal. In a study done using a pilot membrane reactor, ibuprofen can be removed up to 99.1% but diclofenac shows low removal rates of 21.8% due to poor biodegradation in biological treatment. Similarly, a study conducted by Clara et al., (2005) using a membrane bioreactor results in a less efficient diclofenac removal process when compared to conventional wastewater treatment plant as shown in **Table 2.2** probable due to the membrane which does not detain the substances by size exclusion. Alternatively, physical-chemical posttreatment can be used to improve the removal effectiveness of diclofenac from wastewater such as ozonation, reversed osmosis and granular activated carbon (Langenhoff et al., 2013).

Table 2.2 Mean dissolved concentration (ng/L) of diclofenac in inflow and effluent of WWTP and MBR (Clara et al., 2005)

Sampling	**Inflow (ng/L)**	**Effluent**	
		WWTP (ng/L)	MBR (ng/L)
1	3250	1536	3464
2	4114	1533	2033
3	3190	1680	2140

Alternatively, it is possible to use enzymes to degrade the pollutants present in wastewater. The advantages of enzymes over biological treatment and chemical oxidation are the absence of toxic effects, simple and easy control of processes, the absence of unexpected generation of products due to their high specificity, less energy requirement, lack of acclimatization period, and operability at wide temperature range, pH and salinity that are attractive substitutes for traditional wastewater treatment (Sutar and Rathod, 2016). The removal efficiency of the diclofenac was usually less than 50% in the effluent with occasionally negative where effluent have higher diclofenac concentration than the influent. It is possible to be attributed from the unaccounted effects of the DCF-G due to the difficulty sampling the parent compounds and the phase II metabolites from the deconjugation process (Lee et al., 2012). It is possibly true as other study shows diclofenac removal efficiency of 60% under continuous operation of enzymatic membrane reactor with possibility of >80% removal by dosing a redox mediator to the enzymatic membrane reactor (Nguyen et al., 2014).

Adsorbent is another alternative for removal of diclofenac from wastewater. One of the common solid adsorbents is activated carbon due to its surface functionality, hydrophobicity, high surface area and pore structure. However, activated carbon has limited adsorption selectivity and regeneration which limits its application for diclofenac removal. Removal efficiency of 99.7% has been shown to be possible using granular activated carbon albeit with a low concentration of diclofenac at 3 μg/L (Rigobello et al., 2013). Other treatment method is usually added to assist the activated carbon in diclofenac removal process at higher concentration to reduce the regeneration requirement of the process. Activated carbon process can be improved through modification to the adsorbent such as oxidized activated carbon, microwave assisted activated carbon and granular activated carbon (Bhadra et al., 2016).

Carbonaceous adsorbents such as multi-walled carbon nanotubes, graphite/graphene have also shown high efficiency in removing diclofenac sodium from water. Granular carbon nanotubes has shown to be capable of removing 26.5% to 94.5% of diclofenac at a pH of 10 to 4 (Wei et al., 2013). Similarly, surface modified zeolites have also been studied as a possible option on its application for diclofenac sodium removal using cationic surfactant for ion exchange with absorption capacity in the range of 1 to 35 mg/g. The efficiency of the adsorbent materials however mainly depends on the physical and chemical properties of the adsorbates and their interactions with the adsorbents (Bhadra et al., 2016).

Novel adsorbent materials have been studied to improve the currently available adsorbent material on the efficiency and material cost for regeneration. Amphoteric adsorbent coating has been studied for dyes removal with both cationic and anionic functionalities on the adsorbent which could be promising for removal of diclofenac sodium from wastewater (Azha et al., 2018a). Diclofenac sodium forms anions or neutral molecules in water at different pH values. In Liu et al., (2017), removal of diclofenac using the electrostatic attraction between the adsorbents and the diclofenac sodium have been studied with high adsorption capacity, fast adsorption and desorption of diclofenac sodium. Therefore, it is feasible to use an amphoteric absorbent coating in separation of diclofenac from water.

2.5 Adsorption interaction mechanism

Multiple adsorbents have been studied for diclofenac sodium adsorption to target the specific adsorption mechanism in order to effectively remove the diclofenac sodium such as π–π interaction, hydrogen bonding, Van der Waal forces, electrostatic interaction, acid-base interaction and hydrophobicity.

Adsorbent such as carbon nanotubes, activated carbon and its derivatives uses some common mechanisms such as van der Waals forces and π–π interactions involved in DCF adsorption (Feng et al., 2018). The electron-withdrawing carboxyl on the aromatic ring of DCF, in particular, causes the electron-depleted benzene ring (acceptor) of DCF to tightly connect with the graphene sheet (donor) of the adsorbent via π-π interactions.

Acid-base interaction for adsorption has also been studied using Zr-based metal organic structures (UiO-66) as shown in Figure 2.2 (Hasan et al., 2016). The surface charge of UiO-66 remains positive up to a pH of roughly 5.5, but DCF resides in an anionic state when the pH exceeds 4. The preferential adsorption of DCF with UiO-66 was thus due to electrostatic interactions between the DCF anions and the positively charged surface of UiO-66 (particularly at a pH of 5.5). Both DCF and UiO-66 become negatively charged at pH greater than 5.5, considerably limiting DCF adsorption. Furthermore, the lower adsorptions at pH 4.5 may be explained by the higher concentration of neutral DCF at that pH. As a result, electrostatic interactions would play a less role.

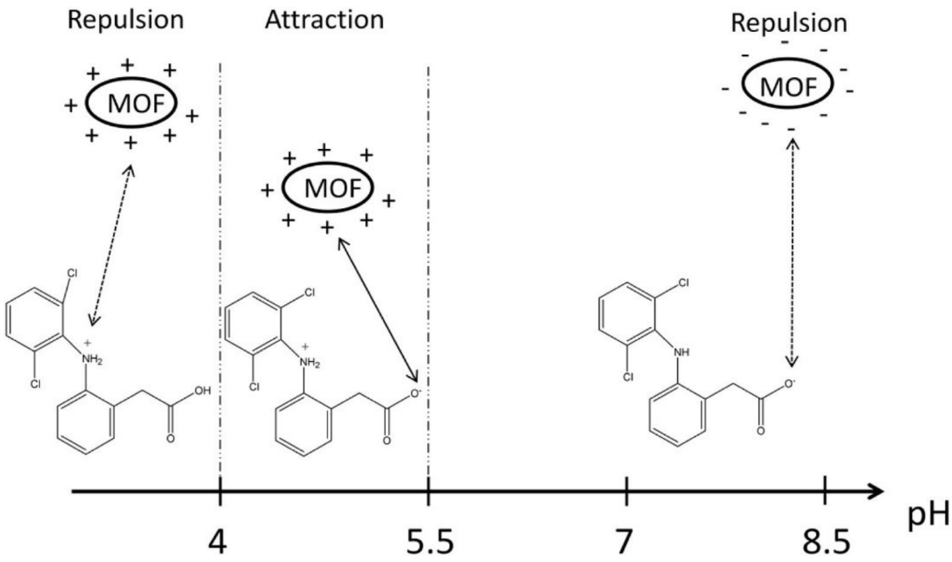


Figure 2.2 Adsorption mechanism UiO-66 for DCF (Hasan et al., 2016)

Hydrophobic interaction was also been previously investigated for its efficacy in removing DCF using graphene oxide, since it was observed that the hydrophobicity of DCF might alter adsorption and had a positive correlation towards the hydrophobic pollutant. Nam et al., (2015). Although the mechanism is not fully explained, increasing the concentration increase of the graphene oxide in the test solution increases the adsorbent's adsorbable surface area in comparison to the comparatively hydrophobic DCF.

2.6 Advanced Wastewater Treatment Plant

Multiple treatment method had been studied to improve the removal efficiency of diclofenac. However, drawbacks and limitations could limit its potential in application on a wastewater treatment plant. To compensate and reduce the drawbacks, multiple treatment process could be combined in a single wastewater treatment plant to introduce the better removal method to a conventional wastewater treatment plant. A study conducted on the available advanced wastewater treatment system in Eastern United States has been conducted on assessing the removal of pharmaceuticals (Angeles et al., 2020). Different results were obtained from the wastewater treatment plants utilizing different designs and treatment technologies as shown in **Table 2.3**.

Table 2.3 Diclofenac removal efficiency of different advanced WWTP with added tretment technologies

WWTP	Additional treatments technologies	Diclofenac removal efficiency (%)
WWTP 1	Granular activated carbon UV radiation	100
WWTP 2	Moving Bed Biofilm Reactor, Tertiary clarifier Filtration	100
WWTP 3	Flocculation sediment Ozonation Biologically activated Filtration Granular Activated carbon	100
WWTP 4	Sequential Batch Reactor UV radiation	40
WWTP 5	Membrane bioreactor UV radiation	-100
WWTP 6	Sequential Batch Reactor Chlorination	-100
WWTP 7	Nitrifying activated sludge Chlorination	13

WWTP 1, WWTP 2 and WWTP 3 shows the possibility for complete removal of diclofenac. Granular activated carbon and ozonation in WWTP 1 and WWTP 2 shows a high removal efficiency of pharmaceuticals. The negative removal efficiency is observed in WWTP 5 and WWTP 6 which could be caused by the transformation of some human or microbiological metabolites to their original compound through deconjugation process. WWTP 7 shows only 13% removal efficiency as nitrifying activated sludge only converts ammonia to nitrate with nitrifying bacteria. The main removal of diclofenac was possibly attributed in the primary treatment stages. WWTP 4 has similar treatment technologies as WWTP 7 but utilizes UV radiation instead of chlorination which proves effective in increasing the removal efficiency to 40%. It should be noted that all the wastewater treatment plants are efficient at removing other pharmaceutical compounds including acetaminophen, citalopram, caffeine, trimethoprim, etc.

CHAPTER 3
METHODOLOGY

This chapter discloses the information on the methods applied in this final year project. It includes the general research flow diagram, research activities schedule, deliverables milestone deadlines and the design of the experiment.

3.1 Overview of Research methodology

Overall, this final year project focused on the performance evaluation of amphoteric absorbent coating in removing diclofenac and determination of its adsorption isotherms. **Figure 3.1** shows the overview of the research activity.

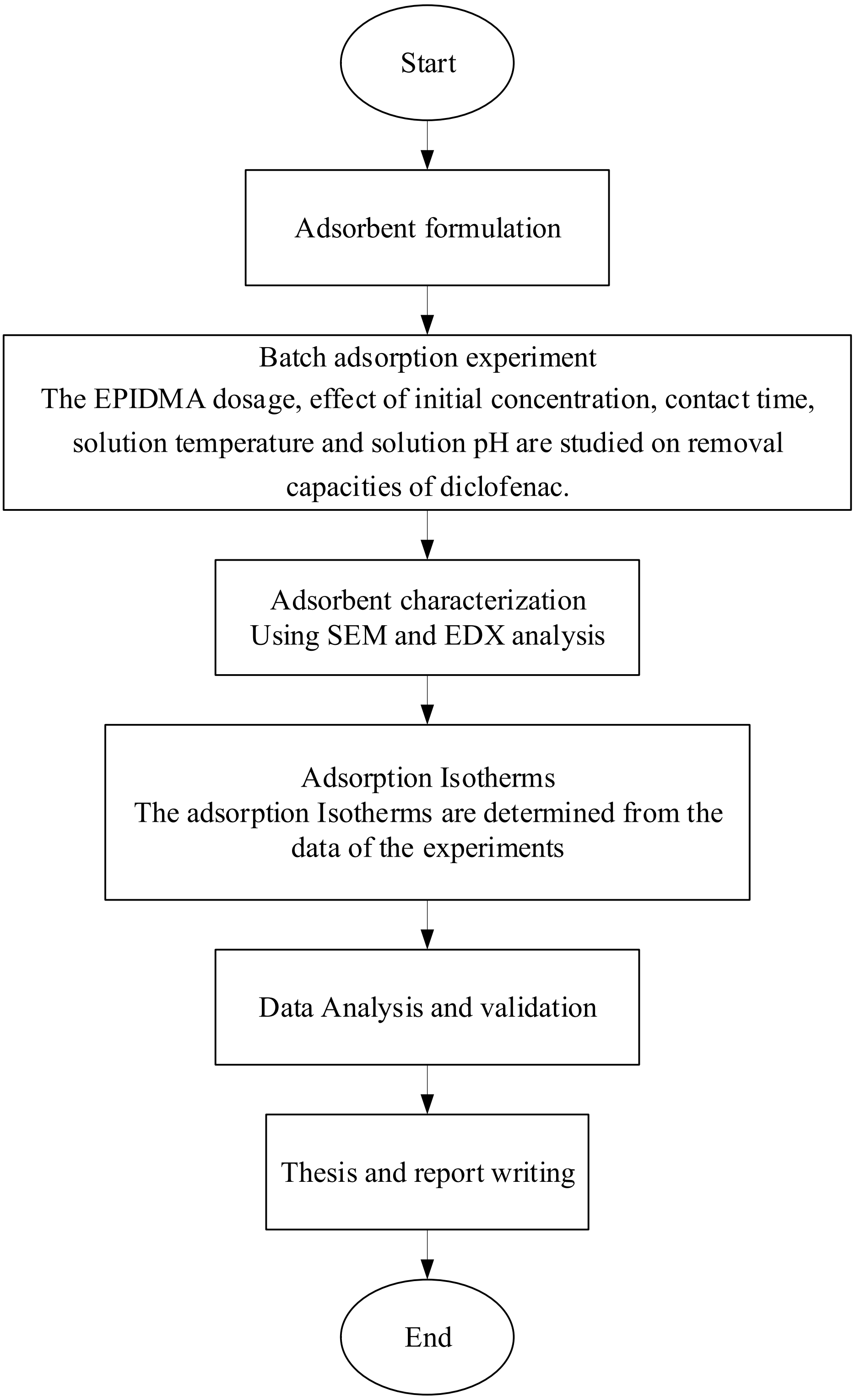


Figure 3.1 Flow diagram of research project on the performance evaluation and determining adsorption capacity of diclofenac removal using AAC.

3.2 Materials and Chemicals used

In this study, the chemicals and materials used includes poly-epichlorohydrin-dimethylamine (EPIDMA), acrylic polymer emulsion (APE) and smectite-based clay for the formulation of the amphoteric adsorbent coating (AAC) which is coated on a cotton cloth for the removal of diclofenac sodium (DCF) which is dissolved in distilled water and Sodium hydroxide (NaOH) and Hydrochloric acid (HCl) is used to adjust the pH. The details on the chemicals and materials used are shown in **Table 3.1**.

Table 3.1 List of chemicals used in the experiment

Materials	Source	Usage
Poly-epichlorohydrin-dimethylamine (EPIDMA)	NHA Scientific Resource, Cyberjaya, Malaysia.	AAC formulation
Acrylic polymer emulsion (APE)	NHA Scientific Resource, Cyberjaya, Malaysia.	AAC formulation
Smectite-based clay	Modern Lab Sdn. Bhd., Malaysia.	AAC formulation
Cotton cloth	Kedai Kain 1 Malaysia, Parit Buntar, Malaysia.	AAC formulation
Diclofenac Sodium (DCF)	Nano Life Quest Sdn. Bhd	For removal study
Sodium hydroxide (NaOH)	Merck, Germany	pH adjustment
Hydrochloric acid (HCl)	Merck, Germany	pH adjustment

3.3 Amphoteric Adsorbent Coating formulation

The preparation method were previously studied by Azha et al., (2018a). The amphoteric absorbent coating (AAC) was formulated using a facile in situ intercalative method with mass ratio of acrylic polymer emulsion (APE), bulk clay and poly-epichlorohydrin-dimethylamine (EPIDMA) at 1:2:4 ratio. The clay undergoes swelling for 5 hours in deionized water by stirring. The bulk clay was then combined into the APE and stirred for 3 hours to form a homogeneous slurry solution. 2 wt.% of EPIDMA was then be dropped into APE/clay slurry solution. The process of mixing was conducted by stirring the slurry for 5 hours at room temperature. A strip of 5 x 20 cm of cotton cloth were physically cut and coated with 2g of APE/clay-EPIDMA using a paint brush on both side of the strip. The adsorbent was dried at 80°C in the oven by clipping one end of the strip to the oven rack until the weight reaches constant value. Excess coating was removed by gently washing the strip with deionized water. The coated strip is then allowed dried in the oven at 80°C for 2 hours. The steps were repeated using 4, 6, 8, 10, 20 wt.% of EPIDMA for the different EPIDMA dosage effect in batch adsorption study.

3.4 Adsorbent characterization

The AAC were inspected using scanning electron microscope, SEM with magnification at 100×, 2000× and 5000× with 10 kV of accelerating voltage for the morphology of the absorbent before and after adsorption. Analysis on the elemental composition was conducted using Energy Dispersive X-ray spectrometry (EDX) to identify the elements in the AAC after adsorption. The characterization of the AAC is conducted using Extreme High Resolution Field Emission Scanning Electron Microscope (XHR-FESEM) Model FEI Verios 460L

3.5 Batch adsorption study

3.5.1 Diclofenac sodium solution preparation

Diclofenac sodium was initially dissolved in deionized water to form the solution. The diclofenac sodium properties are shown in **Table 3.2**. The solution was prepared using 50 mg of diclofenac sodium dissolved with 1L of deionized water in a volumetric flask. The solution was stirred using a magnetic bar at 300 rpm in a stirrer for 2 hours for complete mixing. Other concentration of diclofenac sodium solution was prepared based on the equation below using the 50 mg/L as the initial concentration:

$$C_1V_1 = C_2V_2 \tag{3.1}$$

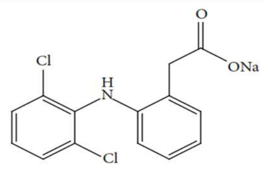
Where C_1 = initial concentration of DCF solution (mg/L)

V_1 = initial volume of DCF solution (L)

C_2 = final concentration of DCF solution (mg/L)

V_2 = final volume of DCF solution (L)

Table 3.2 Properties of Diclofenac sodium

Properties of Diclofenac sodium		**Reference**
Structure		
Molecular weight	318.1 g/mol	pubchem.ncbi.nlm.nih.gov
Molecular formula	$C_{14}H_{10}Cl_2NNaO_2$	pubchem.ncbi.nlm.nih.gov
CAS No.	15307-79-6	pubchem.ncbi.nlm.nih.gov
pKa	4	https://go.drugbank.com
Water solubility	0.00482 mg/mL	https://go.drugbank.com

3.5.2 Calibration Curve

Before the batch adsorption experiment can be conducted, the standard calibration curve of known concentration using Fourier transform infrared spectroscopy (FTIR) needs to be created to achieved accurate measurement of its unknown concentration during the batch adsorption experiment. The wavelength of the 276 nm is used to determine the absorbance of diclofenac sodium. Varied concentration of diclofenac sodium solution was prepared and used to determine its absorbance. With the known concentration for the absorbance, graph of absorbance against the concentration were plotted for the calibration curve to determine unknown concentration during the experiment. Since absorbance increases linearly to the concentration, multiple concentration was taken until R^2 reaches close to 1 to give accurate concentration readings. The calibration curve process was performed using the included software for the FTIR-NICOLET iS10.

3.5.3 Batch Adsorption Experiment

The AAC strip was put in the inside wall diameter of the 250mL glass beaker. It was clipped on the wall of the beaker to prevent the strip from shifting. Diclofenac sodium solution was initially prepared the with 200mL volume of the solution. It was then added into the AAC strip beaker and stirred using a magnetic bar at 300 rpm in a stirrer. The diclofenac concentration was prepared at 50 mg/L, the temperature was regulated at room temperature and the solution pH was set based on the pH of the deionized water. The adsorption study was conducted for 5 hours in order that the maximum adsorption capacity of the AAC strip was achieved. The batch adsorption studies were performed at different EPIDMA dosage of the AAC, concentration, temperature, and pH of the solution as shown on **Table 3.3**. The EPIDMA dosage preparation method is shown previously on the adsorbent preparation section while the concentration of the diclofenac solution preparation is shown on the diclofenac sodium solution preparation section. The temperature of the solution was varied using the included heating function in the stirrer. The solution was initially heated until it reaches the desired temperature before it is poured to the beaker containing the clipped AAC strip for the batch adsorption study. The solution temperature is regularly monitored and controlled at a constant temperature throughout the adsorption process using a thermometer. The top of the beaker was sealed with parafilm to reduce heat loss and evaporation of the solution. The pH of the solution was changed and regulated by gradually adding 0.1M HCL solution to lower the pH and 0.1M NaOH solution to raise the pH with a dropper until the appropriate pH was reached. The pH of the solution was measured using ISFET (ion specific field effect transistor) meters to get an accurate measurement.

Table 3.3 Experimental parameters and its values

Experimental Parameters	**Values**
EPIDMA dosage of the AAC	2, 4, 6, 8 and 10 wt.%
Concentration of the solution	10, 20 30 40 and 50 mg/L
Temperature of the solution	45, 60 and 75°C
pH of the solution	3, 5, 7, 9 and 11

The diclofenac removal efficiency (%) were calculated using the concentration from the adsorption experiments as shown in the equation below:

$$Removal\ efficiency(\%) = \frac{C_0 - C}{C_0} \times 100\% \qquad (3.2)$$

Where C_0 = initial concentration of the diclofenac

C = final concentration of the diclofenac.

The adsorption isotherms were graphically represented as a plotted of adsorption capacity, q_e against the equilibrium concentration, C_e. The adsorption capacity can be calculated using the equation below:

$$Adsorption\ capacity, q_e = \frac{C_0 - C_e}{W} V \tag{3.3}$$

Where C_0 = the initial concentration of diclofenac

C_e = the concentration at equilibrium of diclofenac

W = the dry weight of the adsorbent

V = the volume of the diclofenac aqueous solution.

The dry weight of the adsorbent can be calculated using the equation below:

$$M_{adsorbent} = M_{AAC\ strip} - M_{cotton\ strip} \tag{3.4}$$

Where $M_{adsorbent}$ = the mass of the AAC adsorbent (APE-Bentonite/ EPIDMA adsorbent)

$M_{AAC\ strip}$ = the mass of the AAC with the cotton cloth strip

$M_{cotton\ strip}$ = the mass of the cotton cloth strip before coating

3.6 Comparison with other diclofenac adsorption technique

The optimized condition for diclofenac removal obtained in this work will be compared with other technologies available form literature review. The result was also compared with the experimental data from Azha et al., (2018a). In her work, the AAC are studied on the removal of cationic and anionic dyes. The result has been discussed in the literature review.

3.7 Thesis and report writing

The data and results were presented. In the report writing, interaction between each variable and its effect on removal efficiency of diclofenac sodium was evaluated and discussed. The optimized removal efficiency was also presented accordingly. Conclusion and suggestions were made based on the results obtained.