RIVER TREATMENT USING BIOFILM GROWTH ON COCONUT AND OIL PALM CELLULOSIC FIBRES

LOW WEN PEI

UNIVERSITI TEKNOLOGI MALAYSIA

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requirements for the award of the degree of
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DEDICATION

Dedicated to My beloved father, mother, brothers, sister & *fung lung*

For giving me infinite love, care, blessing with endless support to me.

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ABSTRACT

Many conventional treatments have been proposed to reduce river pollution issues in Malaysia. However, the application of these technologies is still expensive and sophisticated in terms of both operation and management. Recently, natural waste materials have been found to successfully treat different types of pollutants from contaminated water. Therefore, in this study, coconut fibre (CF) and oil palm fibre (OPF), two highly available natural materials in Malaysia have been selected for the development of adsorption and filtration materials. Instead of multi-purpose usage as furniture, slope protections and others, fibres (CF and OPF) can performed as a treatment medium for removing organic and nutrient pollutants, as well as providing an ideal biofilm formation platform to enhance removal rates. The main goal of this study is to develop biofilm on cellulosic fibres (CF and OPF) for organics and nutrients removal in river water and elucidate its adsorption mechanisms using modified empirical model. Desa Bakti River which is one of the polluted rivers in Johor, Malaysia due to domestic effluent discharge from nearby oxidation ponds was chosen as sampling site throughout the study. Initially various amounts of CF and OPF were tested in a jar test. Then, the obtained amount of fibres (CF and OPF) was used for organic and nutrient removal in a fabricated model with 0.2 m^3 of river water at different flow rates. A same study that used the optimum flow rate was conducted again for biofilm developed fibres (CF and OPF). All the results were analyzed using modified empirical model. This model tested various loading rates and the predicted accumulation rate of adsorbates was found to decrease along with the percentage of outflows. It was discovered that CF with an attached biofilm have a higher mass transfer rate than OPF due to the fact that the thickness of the extracellular polymeric substance on CF was less than on OPF. The global mass transfer factor for the developed biofilm CF was found to be highest at 2% outflow, where chemical oxygen demand, total nitrogen and total phosphorus were 1.0067 d^{-1}, 0.4857 d^{-1} and 0.1485 d^{-1} respectively. By using these modified empirical models as an analysis tool, the natural biofilm formation by using both CF and OPF were confirmed based on optimized yield in removal of organics and nutrients from river water.

ABSTRAK

Banyak jenis olahan sungai telah dicadangkan bagi mengurangkan masalah pencemaran sungai di Malaysia. Walau bagaimanapun, penggunaan teknologi ini masih mahal dan canggih dalam operasi dan pengurusan. Kebelakangan ini, bahan-bahan buangan semula jadi telah berjaya mengolah bahan pencemar daripada air tercemar. Oleh itu dalam kajian ini, serat kelapa (CF) dan serat kelapa sawit (OPF) adalah antara dua bahan semula jadi yang tersedia di Malaysia dalam kemajuan teknik penyerapan dan penapisan. Selain digunakan sebagai perabot, perlindungan cerun dan lain-lain, ia juga boleh digunakan sebagai medium olahan untuk mengurangkan bahan pencemar organik dan nutrien, dan juga sebagai asas pembentukan biofilm bagi meningkatkan kadar penyingkiran bahan pencemar. Matlamat utama kajian ini adalah untuk membangunkan biofilm pada serat (CF and OPF) untuk mengurangkan pencemaran organik dan nutrien dalam air sungai dan menjelaskan mekanisme penyerapannya menggunakan model empirikal yang diubahsuai. Sungai Desa Bakti merupakan salah satu sungai yang tercemar di Johor, Malaysia disebabkan oleh pelepasan efluen domestik dari kolam pengoksidaan telah dipilih sebagai lokasi kajian. Pelbagai kuantiti CF dan OPF telah diuji menggunakan uji balang. Kemudian, jumlah yang diperolehi digunakan untuk mengurangkan pencemar organik dan nutrien dalam model yang direka dengan 0.2 m^3 air sungai pada kadar aliran yang berbeza. Kajian yang sama diulang dengan menggunakan kadar aliran optimum yang diperolehi bagi serat (CF and OPF) yang mengandungi biofilm. Keputusan kajian dianalisis menggunakan model empirikal yang telah diubahsuai. Model ini akan diuji dengan pelbagai kadar beban dan kadar bahan serapan yang mungkin terkumpul secara beransur-ansur mengikut peratusan aliran keluar. Biofilm pada CF didapati mempunyai kadar pemindahan jisim yang lebih tinggi dari OPF kerana ketebalan bahan polimer *extracellular* pada CF adalah lebih nipis dari OPF. Faktor pemindahan jisim sejagat bagi CF yang mengandungi biofilm didapati paling tinggi pada masa 2% aliran keluar, yang mana permintaan oksigen kimia, jumlah nitrogen dan jumlah fosforus masing-masing adalah 1,0067 d^{-1}, 0,4857 d^{-1} dan 0,1485 d^{-1}. Oleh itu, dengan menggunakan model empirikal yang telah diubahsuai ini sebagai bahan bantu analisis, pembentukan biofilm semula jadi dengan menggunakan kedua-dua sabut kelapa dan sabut kelapa sawit telah disah berdasarkan hasil yang optimum untuk menyingkirkan organik dan nutrien dalam air sungai.

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LIST OF ABBREVIATIONS

1S1R	-	One State One River Programme
ABB	-	Acid Brilliant Blue
ADF	-	Acid Detergent Fibre
ADL	-	Acid Detergent Lignin
AFM	-	Atomic Force Microscopy
Alum	-	Aluminium Sulfate
AN	-	Ammoniacal Nitrogen
AO7	-	Acid Orange 7
AOAC	-	Association Of Official Agricultural Chemists
APHA	-	American Public Health Association
AR1	-	Anionic Dye Acid Red 1
As^{5+}	-	Arsenic (V) ion
BAC	-	Benzyltetradecyl Ammonium Chloride
BET	-	Brunauer, Emmett and Teller
BOD	-	Biological Oxygen Demand
BRR 160	-	Blue Remazol R160
Ca^{2+}	-	Calcium ion
CAS	-	Conventional Activated Sludge
Cd^{2+}	-	Cadmium ion
CF	-	Coconut Fibre
Co^{2+}	-	Cobalt (II) ion
COD	-	Chemical Oxygen Demand
Cr^{2+}	-	Chromium (II) ion
Cr^{3+}	-	Chromium (III) ion
Cr^{6+}	-	Chromium (IV) ion
Cs^{+}	-	Caesium ion
Cu^{2+}	-	Copper (II) ion

CV	-	Crystal Violet
DID	-	Department of Irrigation and Drainage
DOE	-	Department of Environment
ECPS	-	Easy Care Pipe System
EM	-	Effective Microorganisms
EPMA	-	Electron Probe Macro Analysis
EPS	-	Extracellular Polymeric Substance
$FeCl_3$	-	Iron (III) Chloride
FESEM	-	Field Emission Scanning Electron Microscopy
FFB	-	Flexible Fibre Biofilm
FSS	-	Fixed Suspended Solid
FTIR	-	Fourier Transform Infrared Spectroscopy
H^+	-	Hydrogen ion
H_2SO_4	-	Sulfuric acid
HAB	-	Hexadecyltrimethyl Ammonium Bromide
HCl	-	Hydrochloric Acid
HFR	-	High flow rate at average of 0.1504 L/s
Hg^{2+}	-	Mercury ion
HNO_3	-	Nitric Acid
INWQS	-	Interim National Water Quality Standard
IOG	-	Indanthrene Olive Green
IRBM	-	Integrated River Basin Management
LFR	-	Low flow rate at average of 0.1082 L/s
LZ	-	Zeolite modified by 90 nm lanthanide
MD	-	Methylene Blue Dye
MGB	-	Malachite Green Blue
Mn^{2+}	-	Manganese (II) ion
MPOB	-	Malaysian Palm Oil Board
N	-	Nitrogen
NaCl	-	Sodium Chloride
$NaHCO_3$	-	Sodium Bicarbonate
NaOH	-	Sodium Hydroxide
NDF	-	Neutral Detergent Fibre

NH_3	-	Ammonia Molecule
Ni^{2+}	-	Nickel (II) ion
NO_2^-	-	Nitrite
NO_3^-	-	Nitrate
OM	-	Organic Matter
OPF	-	Oil Palm Fibre
P	-	Phosphorus
Pb^{2+}	-	Lead (II) ion
PO	-	Procion orange
PO_4	-	Phosphate Molecule
PO_4^{3-}	-	Orthophosphate
PVC	-	Polyvinyl Chloride
R S2G	-	Rubi S2G,
R^2	-	Regression
R_a	-	Average Surface Roughness
RB	-	Rhodamine B
RMS	-	Root Mean Square
RR 5R	-	Red Remazol 5R
SEM	-	Scanning Electron Microscopy
SEM-EDS	-	Scanning Electron Microscopy-Energy Dispersive Spectroscopy
SS	-	Suspended Solid
TKN	-	Total kjeldahl Nitrogen
TN	-	Total Nitrogen
TOC	-	Total Organic Carbon
TP	-	Total Phosphorus
TSS	-	Total Suspended Solid
U^{6+}	-	Uranium ion
UTM	-	Universiti Teknologi Malaysia
VR 5R	-	Violet Remazol 5R,
VSS	-	Volatile Suspended Solid
Zn^{2+}	-	Zinc (II) ion

LIST OF SYMBOLS

k_{id}	-	Intraparticle diffusion rate constant (d^{-1})
$[K_La]_f$	-	Film mass transfer factor from Fulazzaky model (d^{-1})
$\propto$	-	Elovich coefficient of initial adsorption rate (mg/g·d)
a	-	Langmuir constant related to saturated monolayer adsorption capacity (mg/g)
A_f	-	Total film surface area (m^2)
b	-	Langmuir constant including the affinity of binding sites (L/mg)
c	-	Interception constant for the Elovich Equation
C_0	-	Initial adsorbate concentration (mg/L)
C_e	-	Equilibrium adsorbate concentration in river water (mg/L)
C_s	-	Concentration of the solute to depart from the column (mg/L)
$C_{s, surface}$	-	Surface is substrate ,concentration at film surface (mg/L)
$C_{s, bulk}$	-	Substrate, concentration in bulk, (mg/L)
$C_{s, in}$	-	Influent concentration of substrate (mg/L)
C_t	-	Adsorbate concentration at time (mg/L)
H	-	Bed depth (m)
k_1	-	Rate constant of first-order adsorption (d^{-1})
k_2	-	Rate constant of second-order adsorption (g/mg·d)
$k_{adsorption}$	-	Rate constant for adsorption
k_{BA}	-	Adams-Bohart model's constant (L/mg d)
k_d	-	Porous diffusion factor or internal mass transfer factor (d^{-1})
$K_{desorption}$	-	Rate constant for desorption
k_f	-	Film mass transfer factor or external mass transfer factor (d^{-1})
K_F	-	Freundlich constant related adsorption capacity (L/mg)

k_g	-	Global mass transfer factor (d^{-1})
K_L	-	External mass transfer coefficient from Morgenroth model (ms^{-1})
m	-	Mass of the adsorbent (g)
n	-	Freundlich constant related to adsorption intensity
N_0	-	Sorption capacity (mg/L)
Q	-	Flow rate of water (L/s)
q_e	-	Amount of adsorbed adsorbate into adsorbent at equilibrium (mg/g)
$q_{e,experiment}$	-	Amount adsorbed NOM into fibres (CF and OPF) at equilibrium through experiment data (mg/g)
q_t	-	Amount of adsorbed adsorbate into adsorbent at time (mg/g)
q_t acc	-	Accumulation of pollutants mass onto fibres (CF and OPF) in a day (mg/g)
S	-	Available surface site on the fibres (CF and OPF)
t	-	Reaction time (d)
V	-	Volume of the river water sample (L)
VLR	-	Volumetric loading rate
w	-	Ratio of the rate constant for adsorption to desorption
θ	-	Fraction of surface site occupied ($0 < \theta < 1$)
a	-	Adsorption mechanism
v	-	Linear flow velocity of water (m/d)
β	-	Elovich coefficient of desorption constant (g/mg)
ρ	-	Density of the adsorbents (g/L)

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CHAPTER 1

INTRODUCTION

1.1 Introduction

In many countries, rivers act as a source of water, food and transport. There is no doubt that rivers are vital carriers of water and nutrients to all areas around the world (Jarvie *et al.*, 2013). Apart from being a rich source of food and water, rivers also use for recreational purposes, tourist attractions, fertile alluvial soil, cultivation and hydropower. Clean river water bodies and riparian zones are important to sustain the natural ecosystems that are in a delicate balance. Unfortunately, rivers also provide an easy way for waste disposal from different sectors, especially the primary sector (agriculture, mining, quarrying, and farming) and the secondary sector (chemical and engineering industries, construction). Excessive amounts of nutrients in the river have caused a lot of problems such as harmful algal blooms, dead zones and fish kills (Belton, 2011). It is found that in developing countries, 70 to 80 percent of the illnesses that especially affect the health of women and children are caused by water contamination (Bhatnagar and Sillanpää, 2010).

There are 89 river systems in Peninsular Malaysia, 78 river systems in Sarawak and 22 river systems in Sabah (Azliza *et al.*, 2012). Water from rivers and streams in Malaysia are utilized extensively, as in many parts of the world. Due to this condition, rivers are important in supporting the development of a nation's social, cultural and economic needs, as well as religious beliefs and supporting the natural food chain (Eh Rak, 2013). The Interim National Water Quality Standard (INWQS) has served as a benchmark of performance for river water quality programs in Malaysia (Mustafa, 2011). In the year 2005, "One State One River Programme (1S1R)" was launched by the Department of Irrigation and Drainage (DID) Malaysia, which targeted to improve the river water's quality to Class II in the year 2015 (Global Environment Centre, 2008). For instance, there were six river restoration and rehabilitation projects in Malaysia, such as RM 30 million for Sungai Pinang, RM 160 million for Sungai Melaka, RM 900 million for Sungai Tebrau, Sungai Skudai, Sungai Segget and Sungai Muda (Eh Rak, 2013). However within a period of five years (2008-2012), the Department of Statistic, Malaysia reports that the percentage of polluted rivers, which are classified as Class III to Class V in INWQS, has increased from 4.9% to 8.6%. At the same time, clean rivers, which are classified as Class I and Class II in INWQS, were reduced from 53.1% to 52.8% (Department of Statistics, 2013).

Less developed countries than Malaysia are in an even worse condition, such as in the case in Sub-Saharan Africa, parts of the Indonesian Seas, and West Africa. These areas are facing serious problem of river pollution, especially from organic and chemical pollution, solid waste, and oil spills which were accessed into the rivers directly (Global International Waters Assessment, February, 2006). In fact, the effluents from industries, and agriculture commonly contain pollutants such as heavy metals, dyes, fertilizers and high nutrients which resulted in huge amounts of wastewaters, all of which are toxic to aquatic life (Adedeji and Adetunji, 2011). In the effort to protect a healthy environment with a variety of flora and fauna as well as to tackle health problems, the discharge limits must be strictly enforced by the government and environmental agencies. At the same time, it is also encouraged to practice sustainable and efficient water treatment methods. However, in a rapidly developing country like Malaysia, the application of conventional wastewater treatment materials like alum, polymer flocculants, ferric chloride, and coal prepared activated carbon for water and wastewater treating purposes is a major challenge for the industrial and agricultural sectors due to its high cost and requirement of huge quantities (Nagda and Ghole, 2008).

In order to reduce the treatment cost, material reuse is one of the sustainable practices where the agricultural and industrial by-products are recycled for a new application. In fact, the use of by-products from agricultural and industrial sectors in water and wastewater treatment was discovered in the previous century. Recently, skepticism on the effectiveness of these natural waste materials in contaminated water treatment due to their physical and chemical characteristics has gained serious attention by various research bodies based on the marketability of a particular country. Some examples of by-materials that are often used for water solutions are: fly ash bagasse (Ahmaruzzaman, 2010), walnut shell (Aydına *et al.*, 2009), waste tires (Skodras *et al.*, 2007) and rice husk (Chowdhury *et al.*, 2011). Among these materials, ion exchangeable of zeolite and the large surface area and high carbon content of fly ash are some popular adsorbents that have commonly been used to remove natural organic matter and nutrients from contaminated water (Karapinar, 2009; Huang *et al.*, 2010; Ahmaruzzaman, 2009). However, natural zeolite is not readily available in Malaysia due to the common sources that it comes from volcanic ashes. Fly ash is usually classified as toxic and problematic because of leachability of heavy metal materials due to its naturally rich metal ion oxides content in natural compositions (Karlfeldt Fedje, *et al.*, 2010). Thus, the present study focuses on the use of coconut fibre (CF) and oil palm fibre (OPF), both of which are natural residual products abundantly available from the agricultural industry in many of the agricultural countries, especially in Malaysia (Food and Agriculture Organization of the United Nations, 2013; Abdullah and Sulaiman, 2013)

1.2 Background of the Study

Due to the high cost and high maintenance of advanced wastewater treatment methods, certain industries and the agricultural sector have released domestic waste into rivers without sufficient and proper treatment. The water flowing into these tributaries has resulted in very bad quality for certain cases in Malaysia. This condition is similar to as the selected location of Desa Bakti’s UTM River

Recently, the presence of an excess concentration of nutrients and organics in Desa Bakti River has caused serious problems such as: eutrophication, harmful algal blooms, and fish kills as shown in Figure 1.1. The river condition is getting worse where the increase of organic and nutrients such as nitrogen and phosphorus are released from the nearby wastewater domestic pond into the river water. This has extremely contaminated the aquatic life. Therefore, it is essential to reduce the nutrients from the water in order to achieve environmental sustainability.

Figure 1.1: The occurrences of algae bloom (on left) and dead fish (on right) in Desa Bakti River, Johor.

This research study promotes sustainable, effective, and low cost technology using natural cellulosic fibre to treat river water. Recently, biofilm based technologies were developed for organic and nutrient treatment purposes. Different biofilm carriers are emerging, necessitating the development for river water treatment. In this study, natural cellulosic fibre (CF and OPF) were introduced as biofilm carriers to treat the pollutants in Desa Bakti River. This is because CF and OPF are two waste materials which occurs abundantly in Malaysia. These waste materials can be adaptively reused from the coconut and palm oil industries, which are significant contributors to Malaysia's economy. According to the Food and Agriculture Organization of the United Nations, annual production of CF is approximately 650,000 tonnes from India, Sri Lanka, Thailand, Indonesia, Malaysia, Vietnam, and the Philippines (Food and Agriculture Organization of the United Nations, 2013). Approximately 29,091 kilo tones of OPF as waste produced annually in Malaysia alone (Abdullah and Sulaiman, 2013). The annual production of CF and OPF from agricultural industry has been continuously increasing, yet the overall utilization is marginal and is not fully tapped (Abas *et al.*, 2011). Therefore, the current study is able to achieve sustainable and environmentally friendly development in Malaysia where the recycled waste materials has used are less expensive as compared to the advanced water treatment methods that involve metal flocculants (Rafatullah *et al.*, 2010).

1.3 Problem Statement

River pollution is an overwhelming problem facing in Malaysia. One of the example issues concerning river pollution is the content of organic and nutrients. Though organic and nutrients are essential substances in river, but in an excessive scale, these substances become pollutants that can heavily harm and affected the living communities in the river. Concerning arises, as the current treatment tools such as alum, polymer flocculants, ferric chloride, and coal prepared activated carbon provided in the market are costly and not very efficient (Nagda and Ghole, 2008). Thus, there are a lot of polluted river has been ignored and remains as it is. One of the example is Desa Bakti River which is located at the river catchments on the UTM campus, Johor, Malaysia. It was affected by domestic effluents from four cells of nearby oxidation ponds. Along the river, the Desa Bakti River was also affected by discharge from the drainage system, encompassing residential and gardening areas as well as nonpoint surface runoff during rainy days. At present, this river water is categorized as a polluted river with the organic and nutrient content being reported to reach Class III (slightly polluted) to Class V (very polluted) according to the Interim National Water Quality Standards (INWQS), Malaysia (Zainudin, 2010).

Then, it was also discovered that the CF and OPF are natural waste materials that highly abundantly in Malaysia and the increase disposal of these fibres (CF and OPF) has also become a major issue which has threatened the natural biodiversity and environment due to the limited disposal area available. Therefore in the study, CF and OPF were selected to be used as biological monitoring techniques and to establish the baseline biological information, especially in organic and nutrient removal from the polluted river water. Besides, it was interesting to discover further on their (CF and OPF) potential ability as natural carriers for biofilm development. As stated in previous study where the biofilm is useful for pollutants degradation but the biofilm carriers by using artificial supports are expensive and have many problems in transportation and storage (Sabzali *et al.*, 2011).

Thus, the study was needed to investigate the effectiveness of agriculture wastes (CF and OPF) used for reducing the over concentration of organic and nutrients from river water and also evaluated the fibres as the natural carriers for the biofilm development.

1.4 Objective of the Study

The objectives of the study are as follows:

1. To evaluate the adsorption capacity of CF and OPF for organic matter removal and to design a fabricated column model as prototype scale test.
2. To evaluate the potential organic and nutrients removal by using coconut fibre (CF) and oil palm fibre (OPF) in the fabricated column model with different flow rates and characterize physiochemical properties of the CF and OPF used for adsorption.
3. To evaluate the potential of CF and OPF as carriers for biofilm development and treatment in reducing organics and nutrients from river by using fabricated column model with optimum flow rate.
4. To examine the performance and predict the accumulation rates of pollutants at various loading rates on natural adsorbents using modified mass transfer empirical models.

1.5 Scope and Limitation of the Study

The sample water of the study was focused on the Desa Bakti River in Malaysia, which was polluted by high amounts of organics and nutrients from nearby sources as shown in the results presented in Section 3.3. The study was delimited to the preparation, implementation, and evaluation of a prototype for CF and OPF to the pollutants in the river. Then, CF and OPF were also used to provide surface attachment for algae and multiple bacteria found within the Desa Bakti River water to form biofilm. The efficiency of biofilm attached CF and OPF to improve the quality of the river were tested, but limited to prototype scale studies. Studies at pilot and full scale on the Desa Bakti River have yet to be done. In fact, the prototype was designed approximate the actual condition of the Desa Bakti River without any disruption on pH, temperature and salinity. Due to time restraints, this study was limited only to certain parameters such as chemical oxygen demand (COD), biological oxygen demand (BOD), total organic carbon (TOC), total suspended solid (TSS), volatile suspended solid (VSS), Fixed suspended solid (FSS), total nitrogen (TN), total phosphorus (TP), orthophosphate (PO_4^{3-}), ammoniacal nitrogen (AN), nitrate (NO_3^-) and nitrite (NO_2^-). The morphological features and physiochemical properties of the cellulosic fibres (CF and OPF) and biofilm attached cellulosic fibres (CF and OPF) were also investigated and observed under Electron Probe Macro Analysis (EPMA), Optical microscope, Field Emission Scanning Electron Microscopy (FESEM), Fourier Transform Infrared Spectroscopy (FTIR), Atomic Force Microscopy (AFM), Acid Detergent Fibre (ADF) test, Neutral Detergent Fibre (ADF) test, Acid Detergent Lignin (ADL) test, ash content test and single point Brunauer, Emmett and Teller (BET) surface area analysis.

Despite the focus of microbiology research as a pure culture, it is a must to introduce new theories in the effectiveness of biofilm attached cellulosic fibres for pollutant removal in engineering and mathematical aspects. Hence, the study was not to further analyse the complex communities of microorganisms attached to CF and OPF. The study was looking for naturally occurring biofilm from the Desa Bakti River where it is unable to control the species of the microorganisms attached onto cellulosic fibres (CF and OPF). The strength, species, and ability of biofilm might be varying for other environments.

1.6 Significance of the Study

The significance of this study is to contribute a new and unique idea on biofilm attached cellulosic fibres (CF and OPF) to reduce problems related to high organic and nutrient concentrations in river water. The study provides empirical models related to the mass transfer resistance of pollutants in water to adsorbents based on data monitored from a fabricated physical model. But before this, the performance of natural CF and OPF for organic and nutrient removal are examined in this study. Also, this will make a comparison between the natural cellulosic fibres and biofilm attached cellulosic fibres in removing the organic and nutrient pollutants from river water. Different concentration of the effluents tested from the fabricated physical model for natural cellulosic fibres and biofilm attached cellulosic fibres provide a significant study in understanding the different pollutants adsorption performance and efficiency from river water. In order to relate findings of performances of biofilm attached cellulosic fibres and natural cellulosic fibres to pollutant removal in river water with physical and chemical mechanism of cellulosic fibres, it the composition of cellulosic fibres before and after river water treatment are also observed under various microstructure analysis.

Numerous new experimental approaches and methodologies have been developed in this study in order to explore new, natural bioremediation technologies to river water treatment. These are important in order to have fresh river water resources and good river water quality in Malaysia. Other regions around the world could benefit from the findings of this study, making them all the more significant. In fact, this study fills the gap found in the available literature on organic and nutrient removal from water using CF and OPF. The study also evaluates the effect of different loading rates of organic and nutrient changes to the effectiveness of CF and OPF.

Furthermore, it is a new approach to use the natural waste materials (CF and OPF) as a carrier for biofilm formation. A sudden increase of the study in the field of biofilm research has led to the interesting progress in the development of new mathematical approaches for studying the effectiveness of biofilm attached cellulosic fibres (CF and OPF) and provides a new insight into basics of biofilm development.

Discovering the knowledge and answering the effectiveness of biofilm attached cellulosic fibres (CF and OPF) in river water treatment is important for the application.

Then, the fabricated physical model in this study is also significant and novel as it represents the river's condition. The fabricated physical model is invested for simulating the real river condition, which is able to avoid errors and failure of the natural and biofilm cellulosic fibres (CF and OPF) during real applications.

Therefore, this study provides a complete view on the possibility of using natural waste material (CF and OPF) applications in treating organic and nutrients from river water and suggests that the reliable solutions to enhance the utilization of natural waste materials and overcome the potential issues. It is also important to provide a low cost and efficient method that is able to work as a simple wastewater treatment plant. Additionally, these findings may be used to explore sustainable practices that encourage further research within both academic and industrial fields. Last but not least, this research promotes the recycling schemes concept using by-products such as cellulosic fibres from coconut and palm oil industries and thus helps reduce industrial solid waste using an environmentally friendly development approach.

1.7 Organization of the Thesis

This dissertation was organized into seven chapters. The sequence of the chapters is arranged according to the objectives and rationale of the research. The six chapters comprises one chapter on research introduction, one chapter on a review of relevant literature, one chapter on research methodology, two chapters on data analysis and results, and one chapter on the conclusion and recommendations.

The first chapter introduces an overview of the components of the research field. This includes the contextual development by providing background information and a summary of the existing problem on the topic of interest. The objectives of the study, the scope and limitation and the significance of the results are also outlined.

Chapter two presents the review of relevant literature, which is different and more detailed than the background provided in the introductory chapter. The literature review focuses on issues that are specifically related to (a) practical river treatment methods (b) the common low cost of natural materials working for pollutant removal (c) the wealth of source materials examined in the study (d) biofilm study and development for water treatment and (e) Fundamental empirical models used in adsorption studies. Collectively, this literature is aided in providing the necessary perspective which this study was conceptualized. A review of these relevant literatures in each of the categories was analysed critically to provide information which directly relates to the study in the last section of the second chapter.

Chapter three, Research Methodology, focuses on those procedures and methods that are used throughout the study. The perspective and outline of study, materials, and methods as well as detailed procedures of each experiment conducted are addressed in the chapter. The comprehensive research plan is also introduced in this chapter in order to show the overall research design protocol. A detailed explanation of the research plan provides the sampling procedures, data collection and analysis procedures for the study. Chapters four through fix are dedicated to the qualitative data analysis and results of the experimental studies that were discussed in chapter three. The data analysis collected is described and transcribed in an effort to learn about new developments in natural bioremediation technology, which is related to the topic of interest. Attention is given to discuss the implications of the findings in an effort to establish the reliability and trustworthiness of the conclusions. Lastly, the conclusion and summary of the study together with suggestions for future studies are derived and presented in chapter seven.

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