REMOVAL OF ESCHERICHIA COLI USING LOW FREQUENCY ELECTROMAGNETIC FIELD IN RIVERBANK FILTRATION

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2019

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by

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Thesis submitted in fulfillment of the

requirements for the degree of

Doctor of Philosophy

April 2019

ACKNOWLEDGEMENT

In the name of Allah s.w.t., the Most Beneficent and the Most Merciful. Alhamdullillah, praises to Allah the Almighty, for granting me capability, strength, and patience throughout the completion of this research study.

First and foremost, I would like to express my deepest appreciation and special gratitude to my supervisor Professor Dr. Ismail Abustan, for guidance, patience, and cooperation throughout this study. His valuable suggestions and encouragement enabled me to handle this project with confidence. I deeply acknowledge my co-supervisor Professor Ir. Dr. Mohd Rizal Arshad and Dr. Nurul Hana Mokhtar Kamal, for their engagement in many constructive discussions and also for knowledge contribution throughout my research progress.

Very special thanks to the Environmental Laboratory technicians, Mrs. Shamsiah Mohd Ali, Mr. Mohammed Nizam Mohd Kamal, and Mr Muhammad Zaini Mohd Zuki, who have helped and supported me in the laboratory works. Their assistance was important in completing this research**.** My gratitude also goes to the Ministry of Higher Education Malaysia for providing LRGS Grant No. 203/PKT/6726001 – River bank/bed Filtration for Drinking Water Source, Abstraction and the HLP Scholarship for providing financial assistant and make it possible for me to complete my research.

My deep gratitude is extended to my beloved husband, Mohammad Husni Jamil, for his tremendous patience and support during the entire stretch of this

PhD program. I would also like to thank my daughters (Fatin Izzati, Fatima Az Zahra, Nur Fashihah and Nur Farhanah) for not complaining about missed family times and for being a true blessing in my life. Besides that, I would like to extend my thanks to my mother Siti Patimah Ahmad and all my siblings, who are giving me courage and keeps supporting me throughout my studies. Their love and understanding has helped me to move forward and finished my study.

Finally yet importantly, I would like to offer my sincere thanks to everyone who have helped me through this journey and given the possibility to complete this dissertation. My thesis would have not been accomplished without the help from each one of them. I will definitely take with me the knowledge and experience I have gained and use them as a guide in the future.

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LIST OF ABBREVIATIONS

AC	Alternating current
APHA	American Public Health Association
BOD	Biochemical Oxygen Demand
CCD	Central composite design
Cl	Chloride
CFD	Computational Fluid Dynamics
CFU	Colony-forming units
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
DOE	Department of Environment
DS	Dissolved solids
EMF	Electromagnetic field
LBM	Lattice Boltzmann Method
LF-EMF	Low frequency electromagnetic field
GWB	Geochemist Workbench
DPM	Dispersed Phase Method
3D	Three Dimensional
ICP	Inductively Coupled Plasma
ICP-OES	Inductively Coupled Plasma-Optical Emission Spectrometer
MPN	Most probable number
MOH	Ministry of Health
mTEC	Modified membrane thermotolerant

NWQS	National Water Quality Standard
PIV	Particle Image Velocimetry
RBF	River Bank Filtration
RSM	Response surface methodology
SADA	Syarikat Air Darul Aman Sdn. Bhd
SS	Suspended solids
TDS	Total dissolved solids
TSS	Total suspended solids
US EPA	United States Environmental Protection Agency
UV	Ultraviolet irradiation
VOC	Volatile Organic Compound
WHO	World Health Organization
WQI	Water Quality Index

LIST OF SYMBOLS

β	Magnetic flux density
f	frequency
D_{coil}	Diameter coil
D_{column}	Diameter column
D	Inside diameter of casing well
I	Coil current
l	Length of column coil
μ_o	Permeability constant
k	Number of factors
L	Length of solenoid
N	Number of coil turns
V	Well volume
H	Height of water column
Q	Flowrate
R^2	Coefficient of determination
Y	Model response of *E. coli* removal
Fe	Iron
$Fe(OH)_3$	iron (III) hydroxide or ferric acid
Fe	Iron
Mn	Manganese
MnO_2	Manganese (IV) dioxide or manganic oxide
NH_3-N	Ammonia nitrogen

LIST OF APPENDICES

PENYINGKIRAN *ESCHERICHIA COLI* BAKTERIA DENGAN MENGGUNAKAN MEDAN ELEKTROMAGNETIK BERFREKUENSI RENDAH DI PENAPISAN TEBING SUNGAI

ABSTRAK

Kadar peningkatan bakteria berbahaya di dalam air sungai adalah dalam kadar membimbangkan kerana boleh membahayakan kesihatan di dalam sistem olahan air minuman konvensional. Satu kaedah rawatan yang baik dalam meningkatkan utiliti air adalah kaedah tapisan tebing sungai (RBF). RBF merupakan kaedah baru di Malaysia yang tidak menggunakan bahan kimia dan merupakan rawatan semulajadi. Walaupun sistem RBF sangat cekap dalam menyingikirkan atau mengurangkan kepekatan bahan pencemar, kadangkala ianya tidak berkesan dalam menyingkirkan bakteria berbahaya terutamanya semasa musim hujan dan musim banjir. Oleh itu, kajian ini dijalankan bertujuan untuk menyingkirkan *Escherichia coli* (E. coli), dan mengurangkan kadar kepekatannya dengan menggunakan medan elektromagnetik berfrekuensi rendah (LF-EMF) sebagai komponen radiasi non ionizing di dalam RBF. Hasil pemantauan kualiti air menunjukkan bahawa kadar kepekatan *E. coli* di dalam air Sungai Kerian dan telaga adalah 2419.6 MPN / 100 mL dan 10.1 MPN / 100 mL. Hasil kajian ini menunjukkan bahawa air yang diambil dari RBF masih memerlukan rawatan lanjut bagi memastikan air tersebut selamat dan bersih untuk kegunaan manusia. Kajian ini dijalankan dengan merekabentuk dan membangunkan peranti LF-EMF menggunakan lima jenis *column* kajian yang mampu mengalirkan medan magnet seragam dalam julat frekuensi 50 Hz dengan kepadatan medan magnet 2 mT, 4 mT, 6 mT, 8 mT, dan 10 mT dalam julat masa yang seragam. Diameter *column* kajian yang digunakan adalah berbeza bagi setiap model yang dihasilkan. Simulasi LF-EMF berjaya dihasilkan dalam

merekabentuk dan menentukan kadar penyingkiran bakteria *E. coli* di dalam air sungai menggunakan frekuensi 50 Hz dengan julat medan magnet 2 hingga 10 mT. *Column* kajian yang paling berkesan adalah *column* berdiameter 50 mm, panjang = 500 mm, pada kadar aliran 50 mL / min yang ditentukan menggunakan kaedah analisis data *response surface methodology* (RSM) dengan mengambil kira masa rawatan dan medan magnet untuk penyingkiran bakteri *E coli*. Data ramalan mengesahkan tentang kecukupan dan kualiti model adalah menggunakan model kuadratik. Masa rawatan yang optimum adalah pada 3.10 jam meggunakan medan magnet 6.86 mT dengan peratus penyingkiran *E. coli* yang diperolehi adalah 83.18%.

REMOVAL OF *ESCHERICHIA COLI* USING LOW FREQUENCY ELECTROMAGNETIC FIELDS IN RIVERBANK FILTRATION

ABSTRACT

An increase of pathogenic bacteria (E. coli) in river water is a concern as it is the main precursor to health hazard disinfection in conventional drinking water treatment systems. One possibility of growing interest in water utilities is the technology of riverbank filtration (RBF). RBF is a new method that could introduce non-chemical techniques and natural treatments in Malaysia. Although RBF systems are efficient in reducing or removing the concentrations of contaminants, they are mostly ineffective in the removal of pathogenic bacteria especially during flood and wet seasons. Therefore, this study aimed to remove *Escherichia coli* (*E. coli*), and reduce the concentration with low-frequency electromagnetic fields (LF-EMF) as a component of the non-ionising radiations in RBF. A water quality monitoring study showed that the initial concentrations of *E. coli* in the water of Sungai Kerian and the tube well were 2419.6 MPN/100 mL and 10.1 MPN/100 mL respectively. This finding signifies that the water abstracted from the RBF well still requires further treatment to ensure the water is safe and clean for human consumption. This research project successfully presents and discusses the design and construction of a LF-EMF device built on five horizontal coiled columns that were capable of producing uniform magnetic fields in the frequency range of 50 Hz, and at varying magnetic field densities of 2 mT, 4 mT, 6 mT, 8 mT, and 10 mT for the same range of exposure times. The coiled column model for the development of the prototype parameters were successfully studied. The LF-EMF simulation was performed to determine the removal of *E. coli* bacteria in the river water induced by a 50 Hz with a range of 2 to 10 mT magnetic field. The most effective column, with a diameter 50 mm, length = 500 mm, and flowrate 50 mL/min, was stimulated and optimised using the response surface methodology (RSM) to obtain the optimal required exposure time and magnetic field for the removal of *E. coli*. The model response was fitted to the quadratic model. The values recommended were under optimal conditions of 3.10 hours exposure time, and 6.86 mT magnetic field, whereby 83.18% *E. coli* removal was achieved.

CHAPTER ONE

INTRODUCTION

1.1 Background

Water is a fundamental need, and one of the most abundant resources (Umar et al., 2017). However, the World Health Organisation (WHO) stated that, in 2012, about 780 million people were without an adequate drinking water (WHO, 2012). Hence, the demand for good quality and clean drinking water has increased, especially among Malaysian consumers. Raw water originating from surface water and groundwater needs to be treated before the water is made potable. According to statistics in 2017, in Malaysia, 500 water treatment plants (WTP) were in operation to treat raw water, and produced about 16,536 million litres per day (MLD) of drinking water to consumers (NWSC, 2017).

Clean and safe water is one of the most pressing global health-affecting and environmental issues. Generally, in Malaysia, surface water is exposed to organic, inorganic, and microbial pathogen contamination due to poor management of septic tanks, wastewater, and agricultural runoff and earthwork products (DOE, 2015). Approximately 99% of water supply for domestic uses in Malaysia originate from surface water such as rivers and streams, while another 1% originate from groundwater (Azlan et al., 2012). The surface water in the country has also been polluted with, for example, biological contaminants such as viruses, bacteria, and protozoa which are capable of causing illnesses in humans like bloody diarrhoea, affecting human health as well as the environment (Gurpreet et al., 2011; Saxena et al., 2015; Adlan et al., 2016).

According to the Department of Environment (DOE) Malaysia's annual report, 48% of the 473 rivers monitored in 2014 have been contaminated by these sources. This high percentage reflects that the water resources in Malaysia are contaminated, and the condition may continue to worsen. Among all the pollutant loads entering surface water, bio-colloids are the major pollutants attributed by wastewater discharge and surface runoff. These bio-colloids usually refer to microorganisms in the water, such as bacteria and protozoa (Coffey et al., 2014). On the other hand, the increase of bacteria typically increases the possibility of microbial contamination (WHO, 2012). About 842,000 death cases involving diarrhoeal illnesses because of drinking water contamination were reported (WHO, 2016). In Malaysia, 1,662,329 water pollution point sources were identified, which comprised of 4,595 manufacturing industries, 9,883 sewage treatment plants, 754 animal farm, 508 agro-based industries, 865 wet markets and 192,710 food services establishments in 2012 (Huang et al., 2015)

The situation can worsen during extreme weathers such as El Nino (drought), and El Nina (floods) that have a great impact on the quality and quantity of the water resource (Delpa et al., 2009; Choi et al., 2012; Nurazim, 2018). According to previous studies, contamination of bacteria significantly increases in surface water during these events (Hadzick et al., 2010; Bobba, 2012; Juahir et al., 2016). This poses more challenges to the authorities in delivering and providing safe drinking water via the conventional treatment system because of the low surface water level, and high pollutant loads (Amin et al., 2014). In general, chemical processes, and biological processes using chlorination and fluoridation are used for bacteria removal in conventional treatment systems (Dastanaie et al., 2007; Oh et al., 2015). The presence of disinfecting chlorine in conventional water treatment systems is a public health issue due to their health hazard to humans (Hamidin et al., 2008; Lourencetti et al., 2012).

Therefore, to ensure a stable and safe drinking water supply, alternative methods for water management are necessary especially during extreme weather conditions.

Riverbank filtering (RBF) is an attractive option that can be applied for effective water treatment. RBF is a technique that covers both shallow groundwater and river water that have crossed through the banks of rivers, or riverbanks to well extractions (Buzek et al., 2012). Most of the suspended and dissolved contaminants, including viruses and pathogenic bacteria, are filtered out as surface water is filtered through aquifer materials, and the sediments of the riverbed (Sandhu et al., 2011). Abstracting of riverbank water can overcome water shortage due to extreme events such as floods and droughts that cause water levels to increase on the ground, or reduce underwater intake pipes, causing disruptions in water transfer to treatment plants (Schubert, 2006). In addition, water extracted from RBF frequently enhances water quality compared to raw river water (Hiscock and Grischek, 2002). There is a sequence of processes involved in reducing the level of pollution in RBF, namely, biodegradation, adsorption, ion exchange, dilution, and physical filtration (Worch et al., 2002).

Although RBF is a capable method for improving surface water quality, it does not abolish the problem. Abstracted well water quality is highly dependent on several factors, such as groundwater and river water quality, temperature and pH of water, water residence time, medium porosity, and oxygen concentrations (Kuehn and Mueller, 2000). According to Levantesi et al. (2010)'s study, the breakthrough of bacteria and turbidity occurred in a shallow drilled well (3 to 6 m) due to the short travel time, especially during monsoon seasons. Meanwhile, in Yamuna River, the RBF reduced only the amount of bacteria (Singh et al., 2010). In addition, inorganic metal leaching, such as iron (Fe) and manganese (Mn), from aquifer sediments may occur. As a result, this condition urges for appropriate treatment applications to further enhance the ability of RBF in bacteria and inorganic substance removal.

Indicator bacteria, including the total coliforms, *Escherichia coli* (*E. coli*), *Enterococci*, and *Clostridium perfringens*, are commonly used to measure drinking and raw water quality (Galfi et al., 2016; Friedler and Gilboa, 2010). The presence of faecal coliform and *E. coli* is likewise a potable water contamination indicator through animal or human faecal matter (Wang et al., 2015; Toole et al., 2014). *E. coli* bacteria indicate the potential presence of pathogenic microorganisms in natural and treated waters. *E. coli* can cause a variety of intestinal and extra-intestinal infections, such as diarrhoea, urinary tract infection, meningitis, peritonitis, septicemia, and gram-negative bacterial pneumonia (Bajpai et al., 2012; Hammerum & Heuer, 2009).

To date, many treatment methods for the removal of *E. coli* have been introduced in treatment plants, such as membrane filtration (Modified, 2002), soil aquifer treatment (Levantesi et al., 2010), slow sand filtration (Bauer et al., 2010), granular activated carbon (GAC) adsorption (Zietzschmann et al., 2016), and advanced oxidation (Tijani et al., 2014). All these methods have long been used in water treatment, and proved effective for bacteria removal. However, there is no information about non-ionising radiation applications in water treatment plants in Malaysia. This method is a better option for new applications in RBF systems based on the requirements of packing materials around the well screen.

Despite the numerous advantages of RBF, it also has several limitations (Hu et al., 2016). Seasonal variations have an impact on the concentrations of *E. coli* in riverbeds, where they increased during the wet seasons (Luther et al., 2015). Therefore, researchers have been conducting studies to explore and develop an efficient but cost-effective method capable of removing the *E. coli* using new application techniques. Low-frequency electromagnetic fields (LF-EMF) are a component of the non-ionising radiations used to treat and control the effective growth of *E. coli* bacteria (Oncul et al., 2016). Application of the LF-EMF on the *E. coli* bacteria has shown that exposure to non-ionising, electromagnetic radiation can induce numerous and quite varied removal effects (Tessaro et al., 2015). Due to the capability of LF-EMF to remove the *E. coli* bacteria, this application was introduced as an alternative technique of *E. coli* removal in RBF. Therefore, evaluating the proposed LF-EMF effects on the RBF system is important to determine its effectiveness for the removal of *E. coli* in drinking water supply. The proposed LF-EMF system before and after being applied in the RBF is as shown in Figure 1.1 below. Based on the previously highlighted background, the issues associated with the background are discussed in the following section.

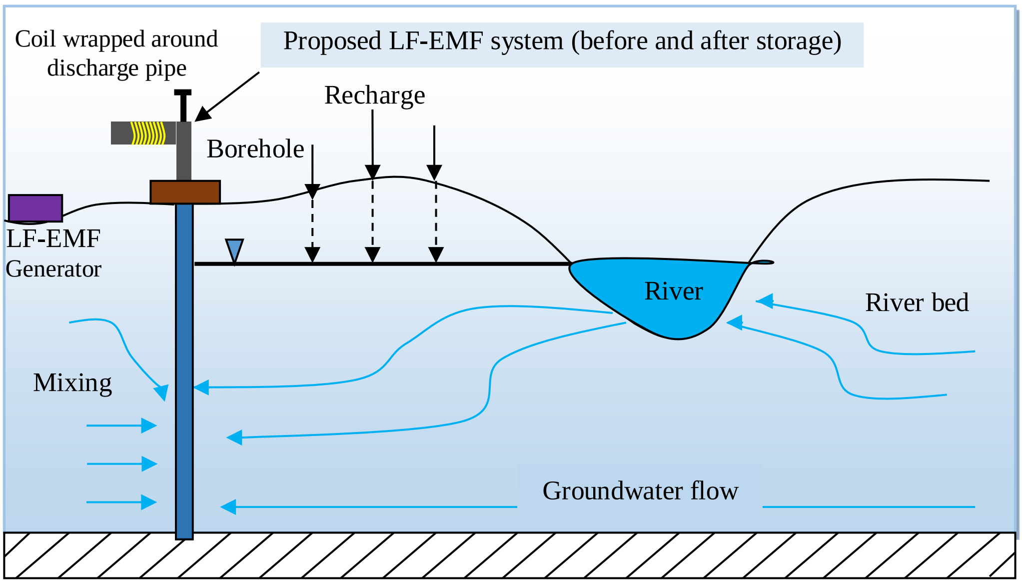

Figure 1.1. Proposed LF-EMF system in riverbank filtration

1.2 Problem Statement

E. coli is one of the most abundant pathogenic bacteria in groundwater sources consisting of a wide range of sewage or animal waste contamination (Farahat et al., 2018), which makes it harder to remove by conventional treatment processes. Chlorine and solar systems are among the methods used for the flocculation and sedimentation of bacterial removal, but turbid waters often limit their effectiveness (Souter et al., 2003). Concentrations of *E. coli* can also be reduced by lowering the disinfection doses that are used, but consequently, this also increases the possibility of waterborne disease occurrences. These limitations can be addressed by the combination of unified flocculant-disinfectant technologies (Sobsey, 2002). Hence, utilising a new method similar to the conventional water treatment is a better solution for the removal of *E. coli*.

RBF is a technology capable of reducing bacteria, chemical contaminants, bio-colloids, and suspended solids at the same time (Shamrukh and Abdel-Wahab, 2008; Dash et al., 2010; Boving et al., 2014). However, the efficiency and mechanism of removal heavily depends on the properties and conditions of the aquifers (hydrological, geochemical, and biological activities). Consequently, the quality of water in abstraction wells varies by the sites. Adlan et al. (2016) reported that the RBF system successfully reduced and removed more than 95% of the total bacteria and total coliform bacteria. However, filtration process through the riverbank aquifers is incapable of fully eliminating the bio-colloids (microorganisms) from river water (Ray et al., 2002). In this case, further treatment is required to continue reducing *E. coli* concentrations to prevent the possibility of harmful disinfection by-product formation. Moreover, the total coliforms (including faecal coliforms, and *E. coli*) must be zero on the presence-absence model based on WHO standards for drinking water quality.

Therefore, some adjustments or enhancements with other treatment techniques can improve the RBF performance.

The application of magnetic fields that independently help in water purification by influencing the physical properties of contaminants in water is well established (Ambashta and Sillanpää, 2010). However, there is no documented information in journals regarding the application of magnetic fields for the bacteria removal process in RBF. In this study, the LF-EMF system was proposed as a treatment technique to improve the performance of RBF in the removing of *E. coli*, where magnetic field intensity plays an important role in determining the success of the treatment process.

Chlorine, chlorine dioxide, ozone, and chloramines are, so far, the most common bacterial and chemical disinfection agents in the drinking water process (Pereira et al., 2011; Revetta et al., 2016). These chemicals are powerful oxidants that oxidise the organic matter naturally present in water, and kill harmful microorganisms effectively (Umar et al., 2011). However, chemical disinfection processes may pose a potential risk to consumers, and also produce disinfection by-products that are residually present in the finished drinking water (Jeong et al., 2015). Based on previous studies, improvement techniques and systems can be produced by using low-frequency electromagnetic fields for the treatment of water to make it free from photogenic microorganisms (Morshed et al., 2010).

In previous research, LF-EMF is mostly used for the removal of *E. coli* and other bacteria in water, with biological effects by magnetic fields (Torgomyan et al., 2012; Oncul et al., 2015). The capability of LF-EMF has been proven although it is dependent on the type of bacteria, the concentration of bacteria, the duration of exposure, the homogeneity of the field, the signal characteristics, and the magnitude of magnetic induction (Brunella et al., 2006; Mihoub et al., 2012; Filipic et al., 2012; Zaidi et al., 2016). Based on a literature search, there are no applications of LF-EMF as a bacterial and chemical disinfection system in RBF despite having its excellent capabilities in *E. coli* removal reported. Additionally, the LF-EMF system was only intensively studied for removing *E. coli* bacteria in surface and groundwater systems. Encouraged by the potential of an application in new areas, LF-EMF was proposed in this study as an improved system for well development after pumping water out of the abstraction well to remove 100% of *E. coli* bacteria.

The presence of a wide range of *E. coli* and total coliforms which have different ionic characteristics and treatment methods makes the removal process more complicated. Additionally, a low field intensity has no or little effect on the bacteria while an excessively strong magnetic field could harm the anammox bacteria (Zaidi et al., 2016). At present, it is important to study the intensity variation of the magnetic field towards the physical properties of *E. coli* removal. Hence, the influence of the magnetic field, exposure time, concentration of *E. coli*, and the intensity of LF-EMF must be investigated. Moreover, the operating parameters of the LF-EMF system used in this enhancement system were also important because different combinations of these parameters will affect the effectiveness of the enhancement. The LF-EMF system used in the current study was different from the other currently available systems as the former used columns updated with different pipe diameters and intensities of magnetic fields. Elimination of 100% *E. coli* at the RBF stage could facilitate providing clean drinking water for maintaining sustainable development and a healthy environment.

1.3 Objectives

This research focused on developing and applying a low-frequency electromagnetic field (LF-EMF) prototype for *E. coli* removal in riverbank filtration (RBF). Hence, the specific objectives of this study are listed as follows:

1) To develop a prototype of LF-EMF in RBF using coiled columns to induce and generate the magnetic fields.
2) To determine the removal rate of *E. coli* using LF-EMF.
3) To evaluate the optimal LF-EMF contact time and magnetic field intensity parameters for the removal of *E-coli*.

1.4 Scope of Work

The study site was located in Lubok Buntar, Kedah Darul Aman at a longitude and latitude of 5°7'37.60"N and 100°35'42.97"E. This area was close to the raw water intake of a SADA (Syarikat Air Darul Aman) water treatment plant at Sungai Kerian. Sungai Kerian is at the border between Perak and Kedah, and is classified as a Class II and III river.

In order to develop and to understand further about RBF, water abstraction information on RBF needs to be explored in order to provide better alternatives for water security sources. Electromagnetic fields, as a component of non-ionising radiations, were proposed in the RBF system to control the bacteria growth, with a focus on *E. coli*, in the river water sample. Pathogenic microorganisms, especially *Escherichia coli*, were chosen to be investigated in the experimental sample as they were widely distributed in the water. Moreover, this study intended to use the 50 Hz frequency at power plugs with Malaysia standard voltage 240V of magnetic field to control the concentration of *E. coli* growth. A constant and steady flowrate was maintained in the prototype horizontal column tests. The columns were exposed to LF-EMF, and AC voltage was used to generate the magnetic field.

Two alternative methods were evaluated in this study—the modified membrane thermotolerant *E. coli* (mTEC) agar (Edberg et al., 1990), and IDEXX Colilert® 18 of the most-probable-number (MPN) method (IDEXX Corporation). The mTEC (1603) is a method recommended by the U.S.EPA (U.S. Environmental Protection Agency), which produces quantifiable results in 24 hours, and provides a direct enumeration of *E. coli* densities. On the other hand, the IDEXX Colilert® 18 method involves the detection of the enzyme β-glucuronidase which is produced by *E. coli*, and therefore, indicates a positive test for *E. coli* (Francy & Darner, 2000).

1.5 Research Significance

The significance of this study is that it provides the enhancement of knowledge in the field of water using non-destructive disinfection systems. More importantly, as pathogens are considered to be of high risk to human health, and potentially present in source water used for drinking, and in potable water systems, this study focused on developing a new technique to remove pathogenic bacteria, such as *E. coli*, in the water source.

1.6 Thesis outline

This thesis was compiled into five chapters. Chapter one briefly provides an introduction of faecal indicator bacteria investigation in raw water intake and potable water. *E. coli* is the main pathogenic bacteria indicator in the WHO and Ministry of Health Malaysia drinking water quality standard. Implementing the RBF system as an alternative for *E. coli* removal, however, has its limitations due to changes in the hydraulic gradient from the river to the aquifers, changes in water temperature, obstruction or clogging of the porous media, and fluctuations in the river stage. These limitations can affect the flow and transport characteristics of the entire RBF system. The operation and design of a new treatment technology of the RBF should be implemented to ensure safe water is delivered to consumers. An overview, the problem statement, and the research objectives were given to identify the research direction to be followed in this study.

Chapter two provides information related to *E. coli* bacteria and RBF. This chapter also covers the types of pollutants in drinking water, water treatment techniques, occurrences of pollutants and bacteria, removal of *E. coli*, and the standard methods of *E. coli* testing. Other than that, this chapter discusses different perspectives of RBF in Malaysia, the principles of electromagnetic field treatment, low-frequency electromagnetic fields, the potential of low-frequency magnetic fields for bacteria removal, and growth control of *E. coli* using electromagnetic fields.

Chapter three shows the flow chart of this research, and the simulations of the LF-EMF model design with elaborations on the steps of the laboratory work in detail. This chapter also presents the column studies and the sampling technique, site location, chemical reagents, and the list of materials used in this present study. This chapter also describes the methods used to determine the removal of *E. coli*, where the Response surface methodology (RSM) was first implemented to obtain optimal parameters for the columns, before proceeding to the column test.

Chapter four presents the results obtained from this study. The LF-EMF prototype design and simulation results were presented. Next, the explanatory statistics provide an overview of *E. coli* and other water quality parameter concentrations in the water samples from Sungai Kerian, and riverbank tube well. After that, the five column tests followed by the *E. coli* removal analysis were discussed. Lastly, an analysis of the optimisation of the column studies using RSM was reported.

Finally, chapter five provides the conclusion to the finding outputs, reflecting all the objectives obtained throughout the study as well as providing recommendations for future research.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Malaysia is rich in water resources, with strong development on providing affordable, sufficient, and easily accessible good quality water to everyone to ensure a healthy population and environment. Water of good quality refers to safe and clean water that is free from harmful compounds that affect its colour, taste and odour. Usually, the quality of drinking water is influenced by the quality of the water resources. Water resource pollution is mostly due to contaminants in the drinking water. Currently, most areas in Malaysia are still dependent on surface water as the main water supply. Nevertheless, the continued deterioration of these resources, along with urbanisation, has become one of the obstacles that need to be addressed (Fulazzaky et al., 2010; Santhi et al., 2012). For example, high concentrations of total coliform bacteria, suspended solids (SS), dissolved solids (DS), total solids (TS), ammonia nitrogen (NH_3-N), dissolved oxygen (DO), biochemical oxygen demand (BOD), and chemical oxygen demand (COD) were observed in several main rivers in Perak which affect the drinking water supply to the population (Ismail & Najib, 2011; Akinbile et al., 2013; Gazzaz et al., 2012; Low et al., 2016). The impact of climate exacerbates the situation by increasing the pollutant load on the surface of the water during flood events, and increasing the concentration of pollutants during the dry season when water decreases through precipitation (Delpla et al., 2009; Figueras & Borrego, 2010; Coffey et al., 2014).

According to Zietzschmann et al. (2016), the formation of pathogens such as *E. coli* bacteria, viruses, and protozoa is an issue of interest in water treatment recently.

The *E. coli* bacteria are commonly used as faecal indicator bacteria as evidenced from the epidemiological studies in WHO Guidelines for Drinking Water Quality (Galfi et al., 2016; Wang et al., 2015; Toole et al., 2012; Bauer et al., 2010). In 1986, the U.S. Environmental Protection Agency (U.S.EPA) recommended that *E. coli*, a faecal coliform bacteria, be used as the best indicator of faecal contamination in recreational water quality standards. *E. coli* is the major factor for many diseases in humans, including outbreaks of haemorrhagic colitis and haemolytic uremic syndrome which occur in the lower part of the gut of warm-blooded animals (Bugarel & Martin, 2016; Chattaway et al., 2011). The World Health Organization has reported 842,000 diarrhoeal deaths from the consumption of contaminated drinking water happening in middle-income countries (WHO, 2016). Furthermore, new sources for microbiological contamination continue to emerge (WHO, 2017). In addition to that, certain microorganisms such as *E. coli* bacteria show high-level resistance to chemical treatments (Falagas et al., 2010). This condition has further complicated water treatment processes in balancing the requirement for disinfectants to kill the pathogenic bacteria. Hence, an alternative treatment process which offers good physical removal of pathogenic bacteria is needed to reduce bacteria growth during the disinfection process.

Malaysia is rich with groundwater as a freshwater source apart from surface water supply, and its demand has been projected to increase by 63% from 2000 to 2050 (Manap et al., 2013). In Malaysia, groundwater is in severe demand where surface water supply is non-existent and inadequate. However, groundwater has only become a highly-sought water source in the recent years because the quality of river water is continually deteriorating while water demand is expected to increase (Shamsuddin et al., 2014). Moreover, low surface water levels at the point of intake during the dry season could prevent water from being pumped to water treatment plants, and consequently stop the supply of clean water to millions of people. One of the groundwater abstraction techniques that has proven be effective in preserving groundwater and treating polluted river water for drinking purposes is the riverbank filtration (RBF) system (Bauer et al., 2011).

RBF has long been recognised as a natural method for surface water treatment (Shamrukh and Wahab, 2008). It is an efficient and low-cost alternative of water treatment for drinking water. During infiltration and underground transport, the processes of filtration, biodegradation, and sorption are significant to improve raw water quality (Partinoudi and Collins, 2007). The RBF system is interesting because it can control and remove contaminants from surface water using low-cost treatment technology (Buzek et al., 2012; Adlan et al., 2016; Hu et al., 2016). It is also an effective method of removing pathogenic bacteria and viruses during the infiltration of surface water (Won et al., 2007; Diem et al., 2013; Hu et al., 2016; Wang et al., 2015). Nonetheless, this method is sensitive to the surrounding activities on the ground, aquifer layer properties, and the physical characteristics of the river water (Kuehn and Mueller, 2000). As a result, the removal efficiency of microbial contaminants at different locations are varied, with less than 2.1 logs removal for *E. coli*, and more than3.2 logs removal of viruses (Weiss et al., 2005). Nevertheless, *E. coli* and other bacteria were still observed in RBF or groundwater wells (Tufenkji et al., 2002; Dash et al., 2010; Cady et al., 2013; Gutierrez et al., 2017). Therefore, some improvements or enhancements with other treatment techniques can increase RBF efficiency.

Numerous potentially economical treatment techniques have been studied in water treatment operations to remove *E. coli* in order to comply with strict regulations and demands for high water quality (Dankovich and Gray, 2011; Inyang and Dickenson, 2015). Among them is the magnetically assisted process. This process independently helps in water purification by influencing the physical properties of contaminants in water (Ambashta and Sillanpaa, 2010). In addition, its combination with other methods allows an improvised and efficient bacteria removal. At the same time, *E. coli* can also be effectively removed using this treatment option. Thus, suitable parameters for the magnetic component aides have a high possibility in the improvisation of the efficiency of *E. coli* removal. However, the most suitable magnetic field intensity is the key factor that determines the success of this improvement process. Many studies have used high frequencies and high intensities of magnetic fields on the water purification technique using magnetic assistance. The low-frequency electromagnetic field (LF-EMF) is an improvement in the magnetically assisted process of *E. coli* removal. The LF-EMF is produced by using a 50 Hz frequency for the power net supply following the standard voltage in Malaysia (220 to 240V). This LF-EMF was proved to be able to remove and kill *E. coli* and other bacteria (Bernabo et al., 2007; Esmekaya et al., 2013; Oncul et al., 2016). Hence, this improvement technique was investigated as an alternative method in drinking water treatment.

2.2 Malaysia's Drinking Water Resources

Malaysia has had abundant and rich water resources throughout the years. The main source of drinking water in Malaysia is groundwater and surface water. Approximately 99% of water for domestic uses in Malaysia are from surface water, while another 1% of the supply is from groundwater (Azrina et al., 2011). Malaysia's internal water sources are estimated to be about 580 km^3/year, with 30% of water production for municipal uses (SPAN, 2015). Water supply from surface water is widely used as drinking water, such as water withdrawn from Sungai Kinta, Sungai Langat, and Sungai Selangor (Razak et al., 2015). Water supply from groundwater intake from a few states in Malaysia such as Terengganu, Kelantan, Perlis, Kedah, Pahang, Sabah, and Sarawak are also used for drinking water (Ong et al., 2007). According to the data published by Suruhanjaya Perkhidmatan Air Negara (SPAN) in 2015, only 1.5% of total groundwater supply is present in Malaysia, and there was an increase in groundwater usage by 3.3% from the year 2014 to 2015 (SPAN, 2015). Nonetheless, the key issue to be considered is the quality of the water sources for drinking water supply. Both surface and groundwater sources are easily affected by the surrounding changes, whether manmade or natural. Therefore, it is important to determine undesired constituents, and monitor the characteristics of the water sources to ensure the pollutants in the water do not exceed the standard limits for water supply stated by the National Water Quality Standards for Malaysia (NWQS), and the Ministry of Health (MOH).

2.2.1 Quality of Water Source

The Department of Environment (DOE) uses the National Water Quality Standards for Malaysia (NWQS) and Water Quality Index (WQI) to evaluate the status of the water source quality (DOE, 2012). The WQI, introduced by the DOE, has been practiced in Malaysia for about 25 years, and serves as the basis for the assessment of environment water quality, while the NWQS classifies the beneficial uses of the water sourse based on WQI (Huang et al., 2015). To design the drinking water quality management system, the assessment of water quality is an important step in determining the possible problems in the quality of the drinking water source. Basically, the characteristics of water quality are determined by physical, chemical, and biological factors to describe the overall condition of the water quality and its suitability for a specific use (Skariyachan et al., 2015). The general water quality parameters, sources, and their significant use in water quality study for surface and groundwater are as listed in Table 2.1.

Table 2.1. An outline of water quality parameters and their significance (Modified from (Kura et al., 2018; Ibrahim, 2018))

Parameter	Sources	Significance
Physical parameters		
Turbidity	▪ Particles from soils and rock minerals ▪ Organic and inorganic matter	▪ Indicates, the concentration of colloidal materials in water. ▪ Increase of microbial activities.
Colour	▪ Natural organic matter, in-organic compounds (Fe, Mn),	▪ Indicates the presence of light absorbable dissolved substances
Total Suspended Solid (TSS)	▪ Industrial wastewater (dyes) ▪ Silt, clay, algae, ▪ Animal farm, ▪ Agriculture, ▪ sewage, ▪ Industries	▪ Indicates anthropogenic loading of suspension materials, ▪ Sedimentation, ▪ High TSS can also indicate river erosion
Temperature (ºC)	▪ Atmospheric condition ▪ Chemical reactions	▪ Increase of temperature influence almost all chemical reaction in water, ▪ Influence microbiological activities, ▪ Influence weathering
Chemical parameters		
pH	▪ Free CO2 lower pH, ▪ HCO3, OH and Silicate raise pH ▪ Rain in contact with atmosphere	▪ pH indicate acidity or alkalinity of water, ▪ low pH increase the weathering activity of water,
Dissolved Oxygen (DO)	▪ Atmosphere, ▪ Rainwater, ▪ Chemical reaction	▪ Influence microbial activities in water, ▪ Indicator to redox or toxic condition in water, pollution indicator

Table 2.1. An outline of water quality parameters and their significance (Modified from (Kura et al., 2018; Ibrahim, 2018))

Parameter	Sources	Significance
Total Dissolved Solids (TDS) Conductivity	▪ Mineral constituents from soils and rocks, major ions ▪ Dissolved constituents in water	▪ Shows the capacity of water to conduct electric current and varies with temperature, ▪ Strongly related to TDS content in water, ▪ Can be used as indicator to seawater intrusion ▪ Reflects the salts materials or mineral ions present in water
Salinity	▪ Dissolve ions	▪ Measure of the ability of a water to resist changes in pH
Alkalinity	▪ Carbonate system, phosphate, silicates	▪ Indicates the presence of in-organic constituents (polyvalent cation) in water particularly Ca2+ and Mg2+,
Total Hardness	▪ Soils and rocks, weathering reaction	▪ Indicator of potential (interfering) precipitation ▪ Combination with Ca and Mg may boost the corrosive activities of water,
Chloride (Cl)	▪ Soils and rocks, ▪ Sewage, ▪ Industrial waste, ▪ Seawater	▪ Cause a salty taste in the water, ▪ Presence of Cl and Na can be indicator to seawater intrusion
Heavy metals (Fe, Mn, As, Cu, Zn, Cr, Pb)	▪ Natural sources such as geological formations (Soils and rocks), ▪ Industrial waste, ▪ Mine area and waters, Landfill	▪ Indicates the water polluted by anthropogenic sources, ▪ Indicate the geological area is not suitable for abstracting drinking water, Most of the metals are hazard to human
Biological parameters		
Bacteria (Total/faecal coliform and E. coli)	▪ Sewage, ▪ Living organisms, ▪ Animal farms	▪ Indicates water pollution by sewage water and/or farming

2.2.2 Types of Drinking Water Source Pollution

Water pollution refers to a situation where water bodies, such as aquifers, groundwater, rivers, lakes, and oceans are contaminated (Choi et al., 2012; Dastanaie et al., 2007). The condition could worsen if pollutants are directly or indirectly discharged into the water bodies before being subjected to adequate treatments to remove the harmful compounds (Donner et al., 2010). Pollutants are normally classified based on their respective groups to match the treatment method. Common examples include pathogens (bacteria, viruses, and protozoa), inorganic pollutants (salts, toxic metals, and acids), cations and anions (phosphates, nitrates, and sulphates), and water-soluble radioactive substances (Azizullah et al., 2010). From previous studies done, the majority of the researchers exerted the harmful effects of water pollution on the ecological system (Zhang et al., 2011). When the drinking water source is contaminated, it can cause great hazards to animals and human health when consumed directly (Zhang et al., 2016; Lozano et al., 2014; Gross et al., 2007).

Drinking water pollution can be divided into different types, such as organic substances, toxic substances, thermal pollution, and ecological pollution (Maeng et al., 2011; Cucurachi et al., 2013), which are illustrated in Figure 2.1.

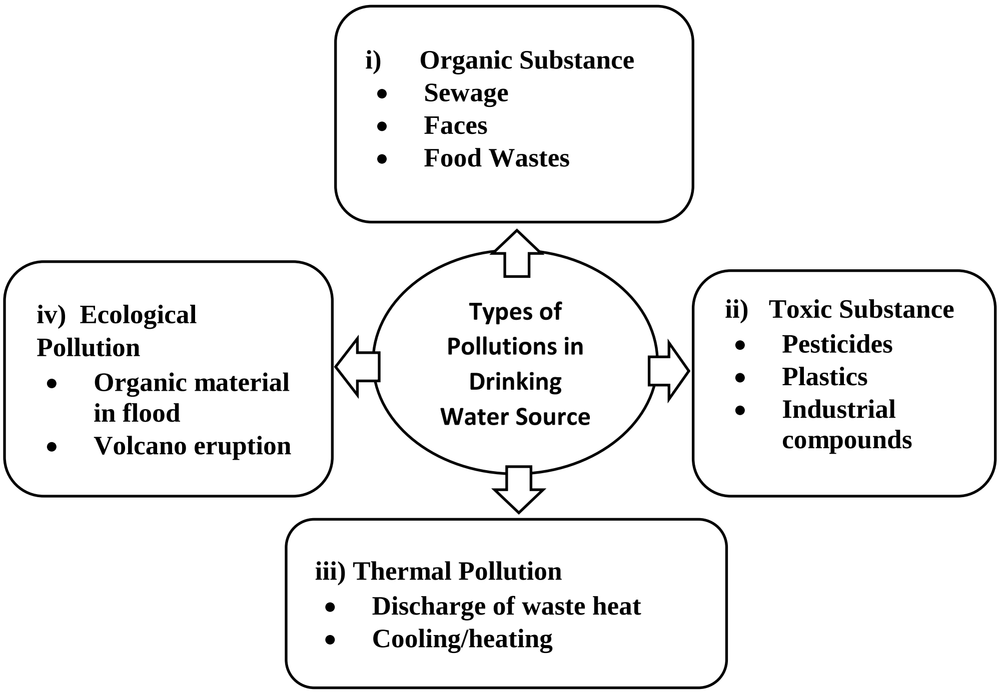

Figure 2.1. Types of drinking water pollution.

Organic pollutants are non-toxic substances containing high organic matter like sewage or manure that enter the waters (Udeigwe et al., 2011). As a result, as the organic matter increases in a water body, the number of decomposers will also experience a simultaneous trend (Sinsabaugh, 2010). Consequently, the decomposers consume a great deal of oxygen to support their growth, and subsequently grow rapidly. Chemical pollutants, on the other hand, are toxic substances of non-natural origins that are present in the aquatic ecosystems (Leszczynska & Kusic, 2012; Malato et al., 2010; Shahawi et al., 2010). Pesticides, herbicides, and industrial compounds are by far the largest contributors of toxic pollution (Post et al., 2012; Murray et al., 2010).

When water bodies are situated nearby any power or industrial plants, the streams are at a high risk of thermal pollution. The industrial discharges often have higher temperatures than the adjacent waters. Continuous discharge may stress the aquatic ecosystem (Schwarz et al., 2010; Zhang et al., 2011) because it decreases the dissolved oxygen level in the water (Olden and Naiman, 2010). At the same time, the oxygen demand of the aquatic organisms soar (Crab et al., 2012). Apart from that, the implications from various human activities can lead to the occurrence of ecological pollution. Ecological pollutants can cause adverse effects on the least tolerant organisms, whereby the high levels of inorganic nitrogen cannot be assimilated by their ecological system functions.

2.3 Occurrence of Microorganism Pollution in Malaysia's Drinking Water Source

The occurrences of pollution and indicator pathogenic bacteria in potable water depend on a number of factors, including the intrinsic and chemical characteristics of the catchment area, and the range of human activities and animal sources that release pathogenic bacteria to the environment. Sources of pathogenic bacteria in potable water are numerous and, for operational efficiency, are typically assessed by faecal indicator bacteria investigation (Kirschenlohr et al., 2012). In terms of biological characteristics for safe drinking water supply and drinking water distribution systems, water is one of the transmission routes for pathogenic microorganisms (WHO, 2012). In spite of having enhanced water management and sanitation, waterborne-diseases and outbreaks may continue to occur (Mwabi et al., 2013). Drinking water polluted by microorganisms of faecal origin is a current worldwide health concern because of epidemic occurrences globally in relation to microbial-contaminated water. In drinking water, these microorganisms of interest include protozoa, bacteria, viruses, algae, and helminths. An overview of these microorganisms is given in Table 2.2.

Table 2.2 Microorganism in drinking water sources; Modified from (Crittenden et al., 2012; Ibrahim 2018)

Types	Description	Remarks
Bacteria Vibrio Cholerae Escherichia coli Legionella Shigella spp Samonella spp	• Single cell organism with size ranging from 0.1 to 10µm. • Negatively charge surface • Aerobic, anaerobic, facultative • Motile and non-motile	• The most reported water-borne plaque are involve of bacteria
Protozoa Cryptosporidium parvum Giardia lamblia Entamoeba dispar Entamoeba histolytica	Group of unicellular and non-photosynthetic organism with diameter size between 1 to 102 µm. Negatively charge surface Aerobic and anerobic Motile and non-motile	Under water-borne disease standpoints, the four listed Protozoa are consider as the greatest risk in water supply
Virus T-4 coliphage Adenovirus Enterovirus Rotavirus MS-2 coliphage	Smallest of waterborne agents with diameter size of 0.02 to 0.2 µm Negatively charge surface	Poliovirus and Hepatitis A are the only known virus that have been documented to be associated with water- borne transmission

Table 2.2 Microorganism in drinking water sources; Modified from (Crittenden et al., 2012; Ibrahim 2018)

Types	Description	Remarks
Algae Volvox Euglena Cyclotella Synedra Chlorella Anabaena	Diameter size: 1 to 102 μm Negatively charge surface Aerobic Motile and non-motile	Algae are common living organism in water supply and play important part in nutrient cycle. But a few algae are pathogenic to human because it produce endotoxins that can cause gastroenteritis
Helminths	Diameter size: 1 to 102 μm Negatively charge surface Aerobic Motile	Effective treatment and disposal of sewage water can control the parasitic worm in water supply

Microorganisms with a range of 1 to 10 μm in particle size are harder to remove by conventional treatment systems, and unfortunately, most of the microorganisms of concern in drinking water fall within this diameter range (Crittenden et al., 2012). These microbiological particles have a consequence on surface effect, which is sediments, and this causes the anionic filter media to become ineffective in removing the particles without repulsion by means of coagulation (Ibrahim, 2018). Additionally, motile microorganisms are harder to remove without prior deactivation by disinfectants. As a measure of the degree of contamination in samples of water, or the degree of the infection in humans and animals, the term 'CFU' (colony-forming units) is used, referring to the number of living bacterial cells.

Chan et al. (2007) carried out a year-long survey of microbiological testing in filtered and non-filtered household drinking water supply in Selangor, Malaysia. They reported that all the collected samples of water contained more than 103 to 104 of CFU/L in total plate counts which does not comply with the Food Act Regulation. This result showed that the presence of total coliforms and *E. coli* were detected in all unfiltered water samples and one of the filtered samples, which indicates that the water is not safe for direct consumption from the distribution pipe. However, many waterborne pathogens are still difficult to detect and quantify in waters, and for most of the newly recognised agents, simple methods to detect them in water samples have yet to be developed.

Water treatment plants, industrial and agricultural activities, and geological conditions are sources of contaminates in the water (Rahmanian et al., 2015). These contaminants are categorised as microorganisms, organics, inorganics, radionuclides, and disinfectants (Levantesi et al., 2010). Of particular interest in this study are the microorganisms in the water supply, which are classified into autochthonous, and allochthonous, where the presence of allochthonous microorganisms seem to dominate the water supply because of water pollution (DOE, 2015). These allochthonous microorganisms thrive in natural water through several sources, including wastewater infiltration to groundwater, wastewater discharge, contamination from rubbish and watershed run-off (Shamsuddin et al., 2014; Al-Badaii et al., 2015; Egervarn et al., 2017). Besides that, according to DOE (2001), in particular, livestock husbandry and agricultural human activities play an important role in contributing to the contamination of river water, among others pollutants. Apart from industrial and agricultural factors, geological conditions is also one of the potential sources of water contamination based on river catchment areas, population density, areas of industry, and anthropogenic activities (Rahmanian et al., 2015).

Populations living in the rural area are more vulnerable to, and easily infected by waterborne diseases (WHO, 2015). In the rural areas, drinking water and water for other daily purposes are taken from the rivers, groundwater, rainwater, or hill water, with limited or no treatment. This condition is worsened with a lack of sanitation and good treatment systems (Ong et al., 2007). According to Payus et al. (2015), the quality of drinking water in rural areas in Sabah was found to be unsuitable to be consumed