WATER QUALITY MONITORING SYSTEM BASED ON MICROFLUIDIC DEVICE

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DEDICATION

I am dedicating this thesis to my father and mother whose guidance, encouragement, love and supports make me able to complete my thesis journey. It is also dedicated to my brother, who taught me time management, planning and motivation.

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ABSTRACT

Water is one of the basic necessities in life. In Malaysia, Ammonia NH3 is found to be one of the main causes of water pollution according to Jabatan Alam Sekitar (JAS). To minimize this issue, this paper proposes an alternative way to detect ammonia content in the river using a microfluidic device. The microfluidic device is based on electrochemical detection that uses an ammonia ion-selective electrode in order to detect the ammonia content in water. The main advantage of this method is able to detect ammonia content in water and short response time. Ammonia ion-selective electrode has a selective membrane which only allows the ammonia ion to pass through. The microfluidic device was designed and simulated in COMSOL software. The proposed microfluidic device will be optimized using finite element analysis (FEA) in COMSOL software and the performance of the proposed microfluidic device will be validated by comparing the simulations' results and the theoretical results. It is found that the proposed solution follows the Nernst equation with a short response time, i.e. 4 seconds. The ion-selective electrode showed an ion-selective towards ammonia ion that only allow ammonia ion to pass through the selective membrane. The proposed solution can be used for ammonia detection in water quality monitoring.

ABSTRAK

Air sangat penting dalam kehidupan. Di Malaysia, ammonia NH_3 merupakan salah satu faktor utama pencemaran air berdasarkan Jabatan Alam Sekitar (JAS). Untuk megatasai masalah ini, laporan ini mencadangkan kaedah alternatif untuk megesan kandungan ammonia di sungai dengan peranti mikro bendalir. Peranti mikro bendalir yang dicadangkan adalah berdasarkan pengesanan elektrokimia yang menuggunakan elektrod selektif ion untuk mengesan kandungan ammonia di sungai. Kelebihan kaedah ini adalah boleh mengesan kandungan ammonia di air dan masa tindak balas yang pendek. Elektrod selektif ammonia ion ada membran selektif, hanya ammonia ion boleh melalui membran selektif tersebut. Peranti mikro bendalir telah direka bentuk dan disimulasi dalam prisian COMSOL. Peranti mikro bendalir yang dicadangkan telah dioptimumkan dengan *finite element analysis (FEA)* dan prestasi peranti mikro bendalir yang dicadangkan telah disahkan dengan membandingkan antara keputusan simulasi dengan keputusan teori. Adalah didapati bahawa penyelesaian yang dicadangkan mengikut Nernt persamaan dan masa tindak balas yang pendek iaitu 4 saat. Ion-selektif elektrod telah menunjukkan pemilihan terhadap ammonia ion saja. Ini disebabkan hanya ammonia ion boleh melalui selektif membran. Penyelesaian yang dicadangkan boleh digunakan dalam pengesanan ammonia di pemantauan kualiti air.

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LIST OF ABBREVIATIONS

2D	-	2 Dimension
FEA	-	Finite Element Analysis
GD	-	Gas Diffusion
IPB	-	Indophenol Blue
ISE	-	Ion Selective Electrode
JAS	-	Jabatan Alam Sekitar
MOH	-	Ministry Of Health
PDMS	-	Polydimethylsiloxane
PMMA	-	Polymethyl methacrylate
PVC	-	Polyvinyl Chloride
WHO	-	World Health Organization

LIST OF SYMBOLS

v	-	Average Velocity
F	-	Faraday Constant
p	-	Pressure
r	-	Radius
Re	-	Reynold Number
A	-	Cross-sectional Area
C_1	-	Concentration of Electrolyte Phase
C_2	-	Concentration of Membrane Phase
C_O	-	Concentration of Oxidation
C_R	-	Concentration of Reduction
d	-	Channel Depth
E_{eq}	-	Electrode Potential in Equilibrium
$E_{eq,0}$	-	Standard Electrode Potential
L	-	Length
n	-	Number of Electron
P_{in}	-	Inlet Pressure
P_{out}	-	Outlet Pressure
P_{wet}	-	Entire Perimeter that Contact with Liquid
R	-	Absolute Gas Constant
T	-	Temperature in Kelvin
V_{in}	-	Inlet Velocity
V_{out}	-	Outlet Velocity
Z_2	-	Charge Number in Membrane Phase
ΔP	-	Pressure Drop Across the Length
μ	-	Dynamic Viscosity
ρ	-	Density of Fluid
Φ_1	-	Potential Difference in Electrolyte Phase
Φ_2	-	Potential Difference in Membrane Phase

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CHAPTER 1

INTRODUCTION

1.1 Problem Background

Water is a basic necessity to all living organisms on earth. Water is essential to our body. The main part of most of the human body's cells is made of water [1]. The human body is about 75 percent water, and is crucial for the continuation of the body's life and homeostasis [2]. Furthermore, water is required for many major industries such as manufacturing, tourism, food and healthcare. Besides that, it is a type of chemical substance that is omnipresent. The chemical formula of water is H_2O which consists of two hydrogen atoms and one oxygen atom. Water plays an important role in maintaining life and survival for all organisms [3]. Water is important, however clean water is even more important [2]. Clean and safe drinking water is important for human health to prevent from common illness [4].

Ammonia nitrogen is an important analyte in the agricultural, biotechnology, and clinical industries [5]. Besides that, nitrogen is important in assisting the formation of amino acids in plants and animals [6]. Nitrogen can be transformed into several forms such as ammonia (NH3) which is a colorless gas with a strong pungent odor. Furthermore, ammonia can be categorized into two chemical substances which are unionized NH_3 and ionized NH_4^+. The greater amounts of ammonia content in water the greater toxicity and higher pH value [7].

In Malaysia, the demand for water has been increased constantly from 8.9 billion m^3 in 1980 to 15.5 billion m^3 in 2000 for agricultural, industrial and domestic purposes [8]. According to the report from Jabatan Alam Sekitar (JAS) in 2017, 477 rivers are considered clean and safe to use. However, 207 rivers are considered moderately polluted and 51 rivers are polluted. Ammonia Nitrogen (NH_3-N) is one of the main substances that caused pollution. Malaysia's water supply is relying on surface water. Besides that, approximately 98% of the potable water supply is treated from both direct extractions from river and dam storage. Ministry of Health (MOH) will monitor and test the water quality via National Drinking Water Quality Surveillance Program at various stages to ensure that the water quality standards are met. According to Malaysia 2013 Report Water Supply Management, there are several locations required to carry out water quality tests which are water supply released from water treatment plants, water supply released from balancing and service reservoirs and in the distribution system before entering the customers' premises.

In 2017, there are incidents of ammonia pollution in Johor, Malaysia. The pollution was caused by the leaking of fertilizer from the fertilizer processing plant and poultry farm. This pollution had affected approximately 2 million residents including Johor Bahru, Kota Tinggi and Kulai. Ranhill SAJ is involved in process of water treatment and distribution of treated water to consumers in Johor areas. Ranhill SAJ had recorded 20 ppm of ammonia in the water which is considered severely dangerous [9]. According to the Ministry of Health (MOH), the only allowed ammonia in water is 1.5 ppm any river that exceeds 1.5 ppm in ammonia is considered polluted and dangerous [10]. The water plant has to halt all operations immediately when the ammonia in water exceeds 1.5 ppm.

Therefore, it will lead to water disruption to the customers. Water disruption causes large economic loss in the industry due to low productivity and decline in production [11]. Moreover, water disruption may affect our daily life. Sanitation and usage of washing machines will be severely affected [1].

1.2 Problem Statement

One of the main causes of pollution is caused by excessive ammonia content in the river bank. Water pollution will lead to water shortages in a certain area. This will lead to inconvenience to agricultural, industrial and most importantly our daily life. Currently, there are several methods for detecting ammonia in water. There are numerous analytical methods such as optical, electrochemical and biological enzyme detection [7]. However, the most common method for detecting ammonia in water is the spectrophotometric Ipratropium Bromide (IPB) method [12]. Spectrophotometric IPB methods required a reacting reagent phenol which is toxic and corrosive [7]. Therefore an alternative method of ammonia detection in water via a microfluidic device is proposed in this paper.

1.3 Research Objectives

The objectives of the research are:

- To design an integrated ion-selective electrode (ISE) with a microfluidic device for detecting ammonia in water.
- To characterize and optimize the integrated ISE microfluidic device using finite element analysis (FEA).
- To validate the performance of the integrated ISE microfluidic device via simulation.

1.4 Research Scopes

The scopes of the project are:

- The simulation of the microfluidic device is based on Finite Element Analysis (FEA) in COMSOL software.
- The characteristic analysis of the Ion-selective electrode is based on physical, electrical and fluid flow analysis.
- Water quality monitoring is based on ammonia detection.

1.5 Report Organization

Chapter 1 describes the introduction, problem background and problem statement. Besides that, the research objectives and research scopes for this project are included in chapter 1.

Chapter 2 explains the literature review of this project. Background studies of microfluidic devices in detecting ammonia in water have been carried out. There are three types of detection which are optical detection, electrochemical detection and biological enzyme detection. Optical detection detects the variation of light intensity, refractive index sensitivity or interference pattern. Furthermore, electrochemical detection is based on oxidation, reduction or redox reaction that depends on the electrode system. Biological enzyme detection is based on a biosensor. The limitations of each detection method have been discussed in this chapter.

Chapter 3 describes the research methodology. This chapter shows the project flow chart and also the technical flow chart. The project flow chart is the overall flow chart for this project. The technical flow chart is the flow chart for the COMSOL simulation. This chapter also includes the procedures of the COMSOL simulation and the design of the microfluidics device.

Furthermore, chapter 4 is the results and discussions. All the results obtained from the COMSOL simulations are included in this chapter. Discussions are made according to the results obtained via the COMSOL simulation.

Chapter 5 is the last chapter for this project. This chapter explains the conclusions and recommendations. Conclusions are made based on the results and discussions. Recommendations describe the future improvement for the integrated ion-selective electrode on a microfluidic device.

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