UNIVERSITI PUTRA MALAYSIA

BORON REMOVAL FROM SCHEDULED WASTE LEACHATE USING HYBRID ADSORPTION-MEMBRANE SYSTEM AUGMENTED WITH TiO2 NANOPARTICLES

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By

ABBA MOHAMMED UMAR

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirement for the Degree of Doctor of Philosophy

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DEDICATION

I dedicate this work to Almighty Allah the creator of mankind and the universe.

Abstract of thesis was presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy.

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Chairperson : Prof. Ir. Hasfalina Binti Che Man, PhD
Faculty : Engineering

Landfilling is the most widely adopted waste disposal technique in most countries across the globe due to its simplicity among other waste disposal methods. However, the production of extremely polluted leachate containing boron from landfill has caused a great deal of concern due to high concentration which is toxic and harmful to the environment. Several treatment technologies including, adsorption, electrocoagulation, chemical coagulation, chemical precipitation and membrane have been reported in eliminating boron from a generated effluent before discharge. However, the application of these methods is being limited by some drawbacks. Low adsorption ability, sludge generation, high chemical costs, and regular membrane fouling during application are just a few of the most visible disadvantages. On this note, the current study synthesizes magnetite (Fe_3O_4) nanoparticles using high energy ball milling (HEBM) technique. The Nano-Fe_3O_4 sorbents were characterized based on scanning electron microscopy (SEM) structure, elemental composition (EDX), surface area analysis (BET), crystallinity (XRD), and functional group analysis (FTIR). The resultant sorbent was coated onto a plastic ball using epoxy resin. The nano-magnetite has multifunctional properties such as superior superparamagnetism, a larger surface area, and is non-toxic. Despite the adsorption ability of Fe_3O_4, there is little information on its use in removing boron from scheduled waste leachate. Optimization on the application of the sorbent was conducted using the response surface methodology (RSM) to determine the optimum dosage, pH, and contact time for boron removal. Based on the optimization studies, the plastic coated sorbent was applied to the hybrid system comprising of three compartments, namely adsorption, settling, and membrane compartment. Initially, at the adsorption section of the hybrid system, the leachate was subjected adsorption process for 250 minutes, using nano-magnetite coated onto the plastic ball as a sorbent. The remedied effluent was examined, and a considerable performance was noticed in the removal efficiencies of boron, turbidity, copper, and zinc with 74.39 %, 77.26%, 94.21%, and 89.62% at 250 minutes contact time, respectively. Though, the (plastic ball coated sorbent) was able to achieve 74.39% boron removal and 2.2 mg/L concentration. However, this concentration is still above the WHO/EU/DOE (0.5-1.0 mg/L) standard limit. Application of further treatment process became imperative to meet the standard discharge limit. On this note, the PBS treated effluent was transferred to the membrane compartment for further polishing. A nano TiO_2 was incorporated into the PVDF-PVD dope to improve the hydrophilicity properties and develop a negatively charge zeta potential on the membrane surface. The formulations encompass different loadings of Nano-TiO_2 (0, 0.5, 1.0, 1.5 and 2.0 wt%), and the developed dopes were flipped using phase inversion techniques. The resultant membranes were characterized. The rejection performance was evaluated based on the boron removal from the leachate. PVDF-PVP with 1.0 wt% loading has proven to be the most hydrophilic with 50.01° contact angle alongside with 223.93 $L/m^{2} \cdot h$ and 96.56 $L/m^{2} \cdot h$ permeability flux for pure water and leachate. Despite the potential of TiO_2 nanoparticles to improve its hydrophilic properties, information on the application of modified hybrid nano PVDF-polyvinyl pyrrolidone (PVP) for boron separation from SWL remains very scarce. In the wake of the optimum performance of 1.0 wt% TiO_2 composite membrane, it was selected and incorporated into the PBS-treated Leachate hybrid system for further polishing. The physicochemical analysis of the treated SWL by the hybrid system revealed that the boron concentration was reduced to 2.2 mg/L at the adsorption compartment. Furthermore, the membrane compartment significantly reduced the boron concentration to 0.43 mg/L, which is far lower than the discharge limit of 1.0 mg/L stipulated by WHO. Finally, the modified hybrid TiO_2 membrane has demonstrated to be effective in relegating boron and other contaminants from schedule waste leachate.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENYINGKIRAN BORON DARIPADA SISA TERJADUAL LARUT LESAP MENGGUNAKAN SISTEM HIBRID MEMBRAN-PENJERAPAN DIIMBUH DENGAN NANOPARTIKEL TiO_2

Oleh

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Pengerusi : Prof. Ir. Hasfalina binti Che Man, PhD
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Pembuangan sampah adalah teknik pelupusan sampah yang paling banyak diguna pakai di kebanyakan negara di seluruh dunia kerana kesederhanaannya di antara kaedah pelupusan sampah yang lain. Walau bagaimanapun, pengeluaran bahan larut lesap yang sangat tercemar yang mengandungi boron dari tempat pembuangan sampah telah menimbulkan banyak kebimbangan kerana kepekatan tinggi yang beracun dan berbahaya bagi alam sekitar. Beberapa teknologi rawatan termasuk, penjerapan, elektrokagulasi, pembekuan kimia, pemendakan kimia dan membran telah dilaporkan dalam menghilangkan boron dari efluen yang dihasilkan sebelum dibuang. Walau bagaimanapun, penggunaan kaedah ini dibatasi oleh beberapa kekurangan. Keupayaan penjerapan yang rendah, penghasilan enapcemar, kos kimia yang tinggi, dan pengotoran membran biasa semasa penggunaan adalah beberapa kelemahan yang paling ketara. Pada catatan ini, kajian semasa mensintesis nanopartikel magnetit (Fe_3O_4) menggunakan pengisar bebola berkuasa tinggi (HEBM). Sorben Nano-Fe_3O_4 dicirikan berdasarkan struktur mikroskopi elektron imbasan (SEM), komposisi unsur (EDX), analisis luas permukaan (BET), kristaliniti (XRD), dan analisis kumpulan fungsional (FTIR). Penyerap yang dihasilkan dilapisi pada bola plastik menggunakan resin epoksi. Nano-magnetit mempunyai sifat multifungsi seperti superparamagnetisme unggul, luas permukaan yang lebih besar, dan tidak beracun. Walaupun kemampuan penjerapan Fe_3O_4, ada sedikit informasi mengenai penggunaannya dalam menyingkir boron dari buangan terjadual. Pengoptimuman penggunaan sorben dilakukan dengan menggunakan metodologi permukaan tindak balas (RSM) untuk menentukan dos, pH, dan waktu kontak yang optimum untuk penyingkiran boron. Berdasarkan kajian pengoptimuman, sorben bersalut plastik digunakan pada sistem hibrid yang terdiri dari tiga petak, iaitu bahagian penjerapan, pengendapan, dan membran. Pada mulanya, pada bahagian penjerapan sistem hibrid, larutan larut mengalami proses penjerapan selama 250 minit, dengan menggunakan nano-magnetit yang dilapisi pada bola plastik sebagai penjerap. Efluen yang diperbaiki diperiksa, dan prestasi yang cukup besar diperhatikan dalam kecekapan penyingkiran boron, kekeruhan, tembaga, dan zink dengan masing-masing 74.39%, 77.26%, 94.21%, dan 89.62% pada waktu hubungan 250 minit. Walaupun, (penjerap bersalut bola plastik) dapat mencapai 74.39% penyingkiran boron dan padapekatan 2.2 mg / L. Walau bagaimanapun, kepekatan ini masih melebihi had

standard WHO / EU / DOE (0.5-1.0 mg / L). Penggunaan proses rawatan selanjutnya menjadi mustahak untuk memenuhi had pembuangan standard. Pada catatan ini, efluen yang dirawat PBS dipindahkan ke petak membran untuk penggilap lebih lanjut. TiO_2 nano dimasukkan ke dalam PVDF-PVD dope untuk meningkatkan sifat hidrofilik dan mengembangkan potensi zeta cas negatif pada permukaan membran. Formulasi merangkumi beban yang berbeza dari Nano-TiO_2 (0, 0.5, 1.0, 1.5 dan 2.0 wt%), dan dop yang dikembangkan dibalik menggunakan teknik inversi fasa. Membran yang dihasilkan dicirikan. Prestasi penolakan dinilai berdasarkan penyingkiran boron dari larut lesap. PVDF-PVP dengan pemuatan 1.0 wt% telah terbukti menjadi yang paling hidrofilik dengan sudut sentuhan 50.01 ° di samping 223.93 L / m^2.j dan 96.56 L / m^2.h fluks kebolehtelapan untuk air tulen dan larut lesap. Walaupun terdapat potensi nanopartikel TiO_2 untuk meningkatkan sifat hidrofiliknya, maklumat mengenai penggunaan hibrida nano PVDF-polyvinyl pyrrolidone (PVP) yang diubah suai untuk pemisahan boron dari larutan sisa terjadual tetap sangat sukar. Berikutan prestasi optimum membran komposit TiO_2 1.0 wt%, ia dipilih dan dimasukkan ke dalam sistem hibrid bahan larut lesap yang dirawat dengan PBS untuk penggilap lebih lanjut. Analisis fizikokimia meresap menunjukkan bahawa kepekatan boron dikurangkan secara signifikan menjadi 0.43 mg / L, yang jauh lebih rendah daripada had pelepasan 1.0 mg / L. Akhirnya, membran TiO_2 hibrid yang telah diubahsuai terbukti berkesan untuk penyingkiran boron dan bahan cemar lain dari larut resap sisa terjadual.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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Date: 12 August 2021

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
COD	Chemical Oxygen Demand
BOD	Biochemical Oxygen Demand
TSS	Total Suspended Solid
NP	Nanoparticles r
TiO_2	Titanium dioxide
DOE	Department of Environmental
FR	Flux Recovery
RFR	Relative Flux Recovery
J	Flux
PBS	Plastic Ball-Sorbent
PVDF	Polyvinylidene Fluoride
PVP	Polyvinyl Pyrrolidone
DMA_C	Dimethylacetamide
g	Gram
h	Hour
H_2SO_4	Sulfuric acid
kg	Kilogram
L	Liter
m	Meter
mg/L	Milligram per liter
NaOH	Sodium hydroxide
SWL	Scheduled Waste Landfill

EDX	Energy Dispersive X—ray Spectroscopy (EDX)
FTIR	Fourier Transform Infra-Red
SEM	Scanning Electron Microscopy
SWL	Scheduled Waste Leachate
HEBM	High Energy Ball Milling
RSM	Response Surface Methodology
FRR	Flux Reduction Ratio

CHAPTER 1

INTRODUCTION

1.1 Background of the study

Over the past years, continued commercial and industrial revolution in many nations around the world goes along with speedy increase in the generation of industrial and municipal solid wastes. This significantly leads to severe environmental, economic and health problems (Salehi et al., 2014). Various waste disposal methods, examples include sanitary landfill, open disposal, incineration, composting, hog feeding, grinding and anaerobic digestion are the most commonly practiced. There are some certain setbacks, which limits the application of these technologies. Due to its simplicity, landfilling is most extensively applied method of waste disposal in Malaysia (Aziz et al., 2010; Ismail and Manaf, 2013). Other category of landfill, including, open dumping, sanitary, and scheduled landfill, ie, waste generated from materials with hazardous characteristics which includes toxicity, flammability, explosively, corrosively and biological infectivity are also applied for waste disposal (Chaaban, 2001). Despite its wide acceptability, the generation of contaminated liquid (leachate) from landfill activities is a major concern, as it posed serious threat to environmental and public health safety (Kulikowska and Klimiuk, 2008).

Leachate is a dark aqueous liquid produced because of rainwater passing over several layers of waste undergoing a series of decomposition phases (Abbas et al., 2009; Robinson, 2005; Wiszniowski et al., 2006). In Malaysia reports have shown that 54.8% of the schedule waste were usually moved into the landfill for final disposal (Aja & Al-kayiem, 2018). Various factors including, location hydrology, landfill age, temperature, landfill depth, moisture content and refuse formation determines the leachate characteristics (Singa et al., 2018; Wang et al., 2004). As stated in commonly used legislation, leachate from landfill must be treated accurately prior to releasing into accepting water surface. Specifications like COD, BOD, BOD/COD ratio, pH, (SS), (NH_3-N), boron and heavy metals can represent the leachate characteristics(Adani, 2000; Lee et al., 2010). Consequently, remedying landfill leachate is necessary for mitigating environmental impacts and complying with statutory requirements before discharging into natural waterways. Ion exchange, chemical oxidation, chemical precipitation, activated carbon, adsorption and reverse osmosis are the various treatment technologies used to treat rebellious organic compounds from landfill leachate. Landfill leachate treatment technologies are categories into three main groups, namely, biological (aerobic or anaerobic), chemical and physical and combination of physical-chemical and biological processes (Gao et al., 2015a; Wiszniowski et al., 2006).

The industrial wastewater discharge are the primary sources for releasing boron to the environment. In Malaysia alone, about 2,918,478.34 metric tons of this wastewater were generated in the year 2015 and this estimation is expected to escalate due to the progressive increase in population (Aja & Al-kayiem, 2018). This justifies the high tendencies of excessive concentration of boron. The boron concentration in natural water and wastewater is in the range of 0.3-100mg/L (Kluczka et al., 2015). However, the concentration may exceed 100mg/L depending on the geology of the surrounding and sewage disposal (Kluczka et al., 2015). In a national leachate survey, it was discovered that landfill leachates had significantly elevated boron concentrations (up to 84 mg/l) (Yoshinaga et., al 2001). The Department of Environment Malaysia and the World Health Organization (WHO) have set standards for boron concentration discharge limits in drinking water to be less than 1.0 mg/L and 0.5 mg/L, respectively, due to the possible adverse health effects on humans. (Aja & Al-kayiem, 2018).

Investigations have revealed that associated high concentration of boron and other heavy metals in leachate causes acute vomiting, nausea, diarrhea, dermatitis and cardiovascular diseases (Donoiu et al., 2018). In addition, boron exhibit a noticeable effect on plants such as meristematic growth in tissues, disruption of roots and leaves, thickening of leaves, cracking of bark growth and interfering with cell formations, alongside with delaying in enzyme reactions (Chen et al., 2019; Patrick & Hening, 1997). Display of yellowish spots on leaves and fruits along with a rapid deterioration and untimely expiration of plants were all due to excess boron (Fujita et al., 2005). Therefore, the need for leachate treatment before the final discharge into the environment is imperative.

Various technologies have been exploited for the ejection of boron from water and wastewater. However, there are some drawbacks associated with the application of these methods, which limit their application. Among the various methods employed for boron removal, include chemical precipitation (Xu & Jiang, 2008), activated carbon(Chen et al., 2020a; Foo et al., 2013), electrocoagulation (Jiang et al., 2006; Jiang et al., 2006; Savas, 2007), chemical coagulation (Yilmaz et al., 2007) and reverse osmosis (Figueras & Borrego, 2010). The later method is considered most promising technique for boron removal because of its simplicity in operation and economical sustainability (Cengeloglu et al., 2008; Gao et al., 2011) Among the most sophisticated and versatile techniques for wastewater treatment, drinking and ultra-pure water production, water recycling, and desalination are membrane-based purification processes (Environ et al., 2011). However, its application is being limited by fouling which outturn in a reduction in flux and rejection. Blending in titanium dioxide nanoparticles (TiO_2) into membrane dope improve the hydrophilicity of the membrane, enhance flux and mitigate the fouling problem on the membrane surface (Bae & Tak, 2005; Oh et al., 2009). On this note,the present study incooperated TiO_2 nanoparticles into the membrane dope to make the membrane matrix structure hydeophilic and more negatively charge to remove boron from SWL. Moreso, the present research work is the first to utilize TiO_2 to remove boron from SWL

Owing to the various difficulties and economic disadvantages of those technologies, it has necessitated researchers to conduct new investigations to produce a robust and economical method that will remove boron from water and wastewater effectively. In view of this, the current study focused on developing a system of adsorption membrane to remove boron and metals of interest such as Zn and Cu from landfill leachate. They were chosen based on their industrial applications and potential pollution impact on the environment. Metals of interest were Zn, Cd, Cu , and Pb.

1.2 Problem Statement

Boron is used as a constituent in cosmetic items, soap, glass, and ceramics as well as in medical fields (Hanashima, 2005). Boron in leachate originates from incineration ash, glass and ceramics etc. Elevated boron content in schedule waste leachate could result to environmental and public health problem (Dydo et al., 2005a; Fujita et al., 2005). Literatures have reported concentration of boron in SWL ranging (6.5-31 mg/L) (Hanira et al., 2017; Sani et al., 2014). However, even after physical-chemial treatment this concentration still remains above 4 mg/L. Removal of Boron from real SWL has not been exploited, most of the reported studies that utilzes single aqueous solution (Kluczka, J. 2015; Joanna and Bryjak 2013). In the actual SWL, many interaction between heavy metals and boron could occur at different pH which could interfere the removal of Boron. Therefore, integration system could be able to reduce the Boron to the standard A limits. On this note, it is important to treat Scheduled Waste Landfill before releasing it to the natural environment.

Several technologies have been applied for the removal of Boron from water and wastewater. However, there are some drawbacks associated with the application of these methods, which limit their application. Boron is an amphoteric compound which exist as either boric acid (B_3OH_3) or borate ion ($B(OH)_4^-$) ion depending on the pH. Treatment of boron using conventional treatment method has proven to be very difficult (Hanashima, 2005), due to the antiseptic nature of inorganic boron compounds; on this note, conventional biological treatment methods is inefficient for boron removal from wastewater. Also, other treatment methods such as coagulation sedimentation where aluminium salt and calcium salt are used as coagulants, requires huge amount of chemicals which is unsustainable, in this case, boron is either adsorbed or react with calcium aluminate which is generated when pH is adjusted in the range of 12–13 in the presence of aluminium ions. For example, when 8400 mg/L of aluminium sulphate is added under pH 12.35, the 50 mg/L Boron concentration in the raw wastewater is reduced to 1.3 mg/L(Hanashima, 2005). However, the huge amount of chemicals and the sludge generated in this method makes it economically unviable, which limit the application of this technology. Furthermore, in membrane separation technology, boric acid is hard to be removed by size exclusion because the molecular size of boric acid is about 0.4 nm in diameter, which less than the diameter of most membranes (Henmi et al., 2010).

The adsorption process is considered to be one of the most effective methods for Boron removal due to its low cost, easy operability, remarkable and recycling performance (Chen et al., 2020a; Foo et al., 2013). Numerous adsorbents have been studied for boron removal including, activated carbon. However, the boron adsorption capacity of these materials is relatively low and are not economically viable to apply in full-scale boron-containing wastewater treatment. In particular, the nano-magnetite (Fe_3O_4) precursor exhibits multifunctional properties including superior superparamagnetism,wider surface area, and non-toxicity (Kashif et al., 2018). These unique properties make it a suitable and robust precursor for the adsorptive removal of boron (Feng et al., 2012a). Despite the adsorption potential of Nano-Fe_3O_4, information on its application for removal of boron from scheduled waste leachate remains very limited.

Membrane technology, for example reverse osmosis, has proven to be effective for removing boron from leachate (Prats et al., 2000). The primary disadvantage that restricts the application of reverse osmosis and ultrafiltration as a potential candidate for boron removal from leachate is the high-energy demand and membrane fouling. Therefore, in order to minimize the fouling challenges, the use of hydrophilic nanoparticle additives to modify the membrane is widely practiced by researchers (Mauter et al., 2011; Zinadini et al., 2017). Despite the potential of the membrane filtration technique for the separation process and the potential of TiO_2 nanoparticles to improve its hydrophilic properties, information on the application of modified hybrid nano PVDF-polyvinyl pyrrolidone (PVP) for boron separation from scheduled waste leachate remains very scarce.

Due to the various difficulties and economic disadvantages of those reviewed technologies in removing boron, cost-effective method by combining adsorption and membrane should be considered. In this view, the current study synthesizes magnetite nanoparticles (Fe_3O_4) using HEBM, developed a hollow fibre membrane at varied TiO_2 concentration and evaluated the performance of an integrated adsorption and membrane filtration on boron removal from scheduled waste leachate. This research showed a promising way to reuse the excess mill chips wastes produced in steel industries in Malaysia and also to control boron pollution at a low cost using nanomagnetite.

1.3 Research Objectives

The main objective of the present study is to boron removal from scheduled waste leachate by using hybrid adsorption-membrane system augmented with TiO_2 nanoparticles: boron removal from schedule waste leachate
The specific objectives are:

1. To synthesize magnetic nanoparticles (Fe_3O_4) from mill scale waste and coat onto Cosmo ball.
2. To develop a hollow fibre PVDF/PVP/DMA_C membrane augmented with different dosages of TiO_2 nanoparticles.
3. To characterize scheduled waste leachate derived from a SWL facility and to evaluate the performance of an integrated adsorption and membrane filtration system on boron removal from scheduled waste leachate.

1.4 Scope of the study

In this study the physicochemical characteristics of scheduled waste leachate collected from schedule waste treatment plant facility in Malaysia was investigated. A magnetic nanoparticle (Fe_3O_4) was synthesize from a locally sourced mill scale waste using high energy ball milling technique. A hollow fibre PVDF/PVP/DMA_C membrane with TiO_2 loading (0, 0.5, 1.0 and 2 wt %) was fabricated at the Advance Membrane Technology Centre, Universiti Technology Malaysia. The fabricated membrane was characterized using EDX, SEM, FTIR, porosity, flux and boron removal. Adsorption studies was conducted using aqueous Boron solution to determine the optimum boron removal efficienct at concentration (10-100 mg/L), pH (4-9), contact time (20-240 min) and dosage (0.1-0.6g). However for hybrid study by continous adsorption-membrane filtration system, the real SWL leachate was used. The performance of an integrated adsorption and membrane filtration system on boron removal from scheduled waste leachate was evaluated.

1.5 Thesis Structure

The synthesis of magnetic nanoparticles and development of a TiO_2 hybrid membrane to enhance the hydrophilicity and boron removal from leachate is reported in this thesis. The start-up approach includes investigating the physicochemical properties of schedule waste leachate obtained from a wastewater treatment plant. Magnetic nanoparticles coated onto PB sorbent and TiO_2 hybrid membrane was used for boron rejection. CHAPTER 1 provides information on the introductory aspect of the study, problem statement, research objectives and scope of the study. CHAPTER 2 presents literature on schedule waste landfill leachate, including, classification, characteristics, treatment procedure/method, adsorption and hybrid membrane for boron treatment. CHAPTER 3 describes the experimental layout, materials and methods used in the study. CHAPTER 4 shows the results of each experiment conducted in respect of sorbent and membrane characterization. CHAPTER 5 presents the conclusion and recommendations of the study.

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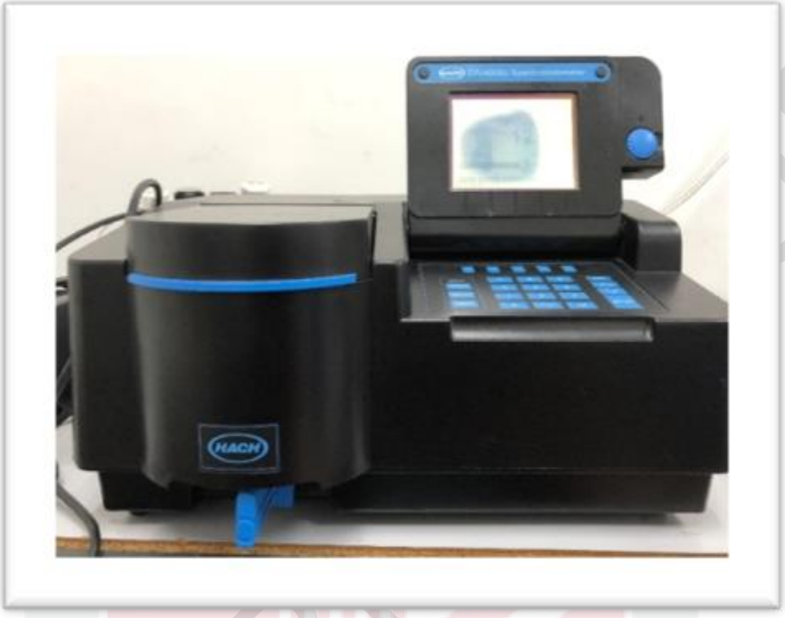
APPENDICES

Appendix A
(Analytical equipment used in the study)



HACH spectrophotometer (DR 4000U)

in-situ YSI meter

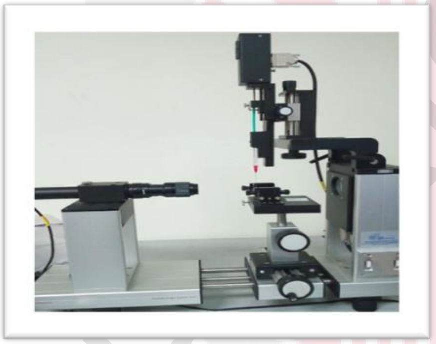
HACH DR/890 Calorimeter

HACH COD Reactor

FTIR machine; Perkin Elmer (S-3400N), MCL

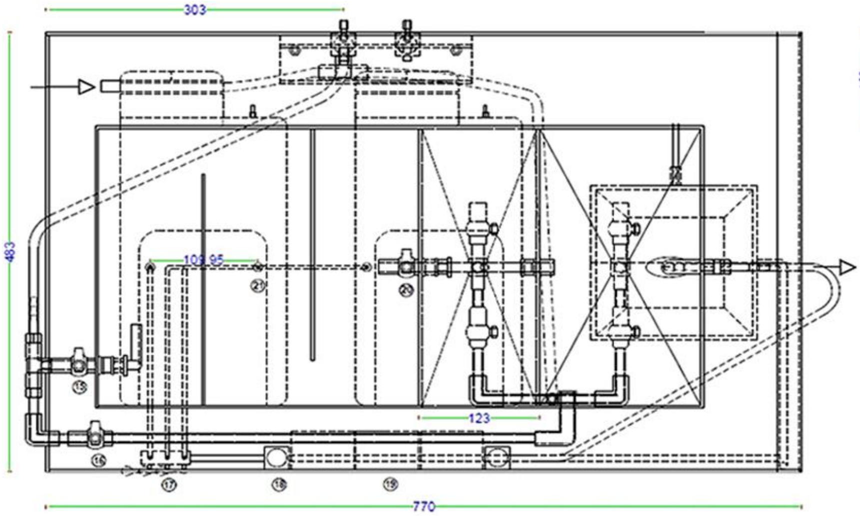
Scanning Electron Microscope spectrum 100 Series, MCL

Digital pH tester

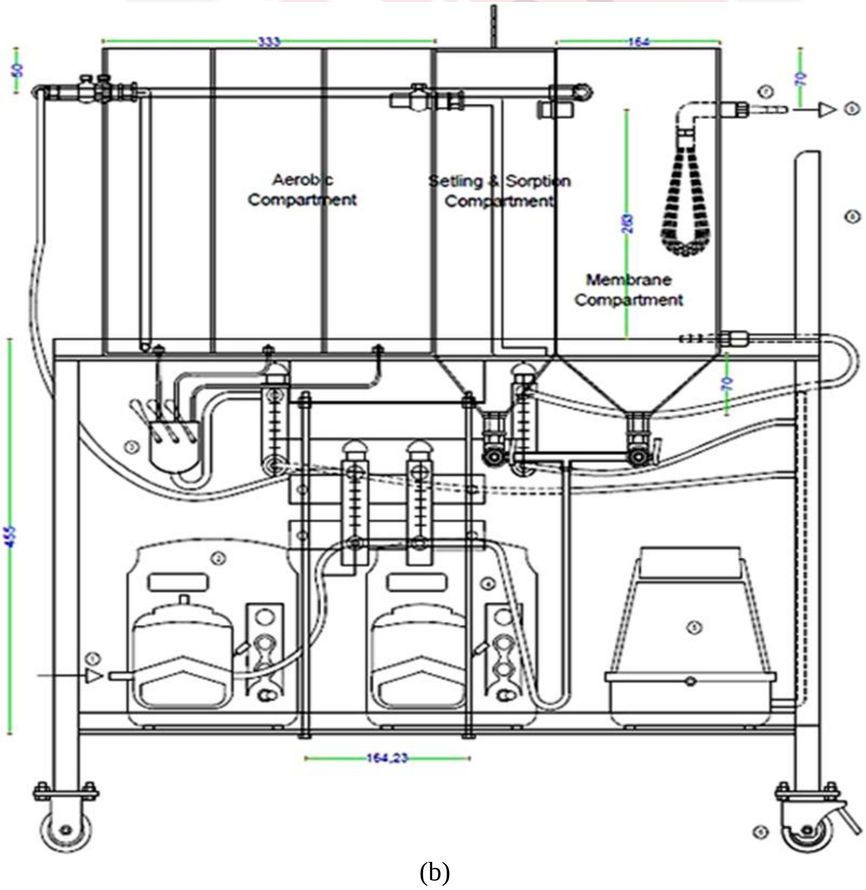


Goniometer
(GmbH OCA 15pro, Data-Physics)
(UTM, Jahor Bahru)

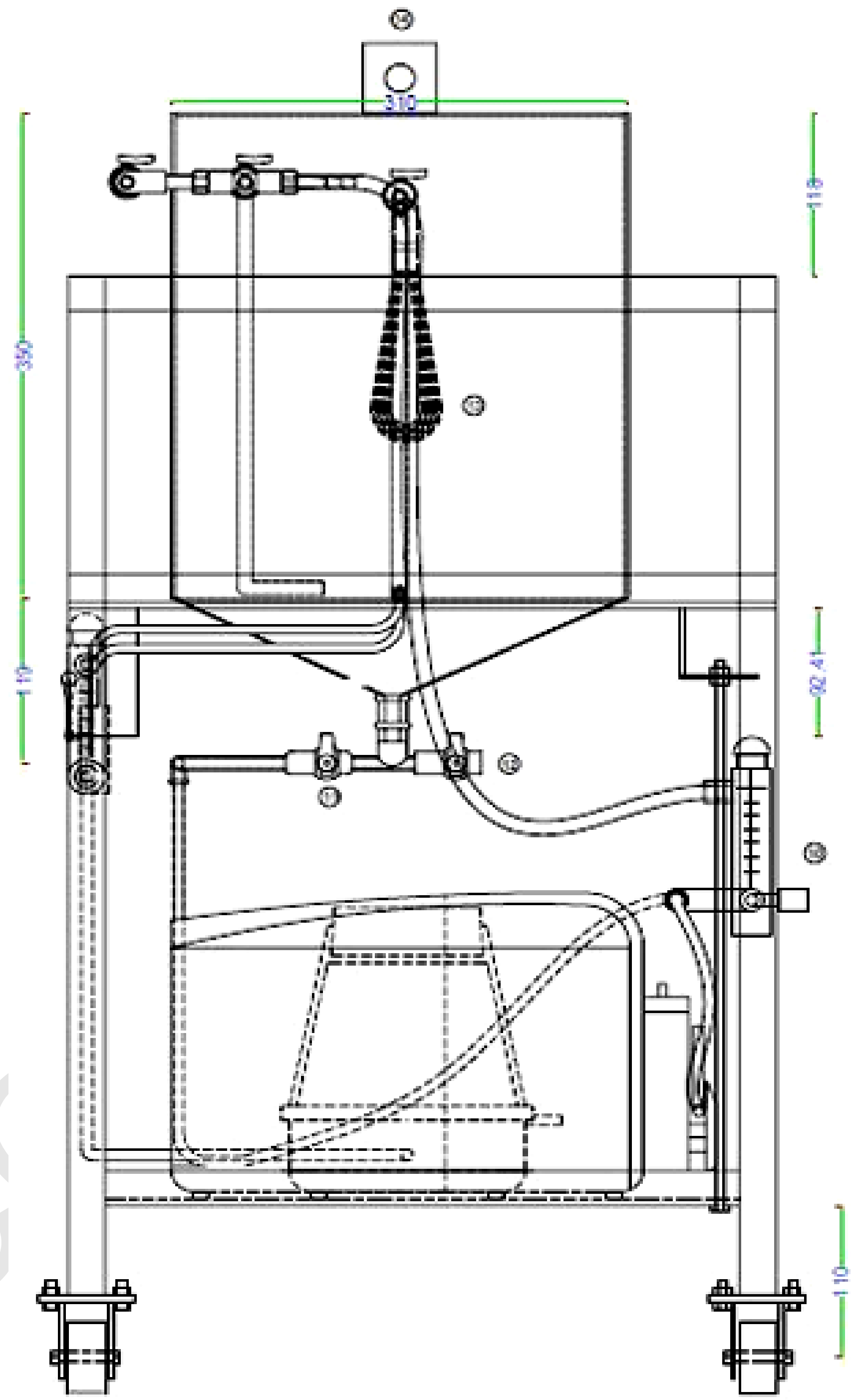
Digital Ultrasonic Water
Bath WR 142-0300
(UTM, Jahor Bahru


303
103
483
109.95
123
770

(a)


333
164
50
70
Aerobic Compartment
Setling & Sorption Compartment
Membrane Compartment
283
70
455
164,23

(b)



(c)

Orthographic showing (a) plan view, (b) front view, and (c) side view of the HMBR system (all dimensions are in mm). Adopted from (Mohammed, 2019)

Experimental set up

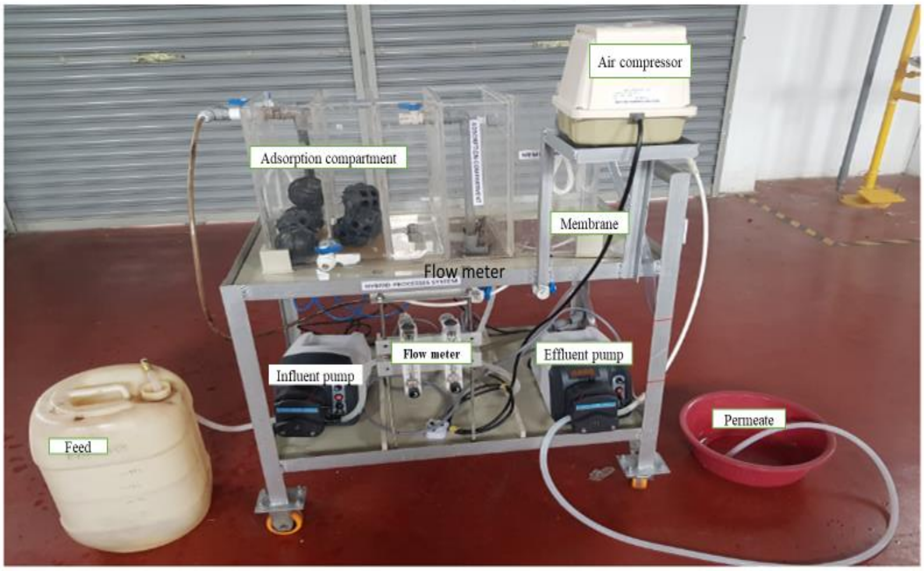


Table 1: Boron standard limits

Bodies	Standard A	Standard B	Reference
DOE	1 mg/L	4 mg/L	(DOE, 2010)
WHO	2.4 mg/L	-----	(Dydo et al., 2005b)
EU	1 mg/L	-----	(Dydo et al., 2005b)

Table 2: Comparison between Physicochemical Properties of Leachate and DOE Standard

Parameter	Unit	Untreated sample	DOE Standard*	Treated sample
pH	---	9.59	5.5-9.0	9.0
NH_3-N	mg/L	347	20	203
TSS	mg/L	2000	100	300
Turbidity	NTU	321	NA	51
COD	mg/L	2250	200	103
BOD_5	mg/L	327	50	366
Nickel	mg/L	0.58	1.0	0.33
Copper	mg/L	2.42	1.0	0.056
Boron	mg/L	8.2	1.0	0.43
Zinc	mg/L	1.06	2.0	0.042
Color	mg/L	229	200	65

Summary of Membrane properties

(a) Neat membrane

i. Length = L = h = 40 cm $\approx 0.4m$

ii. External diameter = 983 nm

iii. Internal diameter = 497 nm

iv. Radius = $(\frac{983-497}{2}) \times 10^{-6} \approx 0.000243\ m$

v. Number of membranes potted per module = 25

vi. R = 25 x 0.000243 $\approx 0.006075\ m$

vii. Area = 2πrh = 2 x 3.142 x 0.006075 x 0.4 $\approx 0.01527012\ m^2$

Flux = $\frac{Volume}{Area \times Time}$

Volume = 63 ml $\approx 0.063\ L$

Time = 2 min. $\approx 0.0333\ hrs$

Flux = $\frac{0.063}{0.01527012 \times 0.0333}$

Flux = 125 L/m^2 h

(b) Modified membrane (1.0 wt% loading)

i. Length = L = h = 40 cm ≈0.4m

ii. External diameter = 963 nm

iii. Internal diameter = 450 nm

iv. Radius = $(\frac{963-450}{2}) \times 10^{-6} \approx 2.57 \times 10^{-4} m$

v. Number of membranes potted per module = 25

vi. R = 25 x 2.57$\times 10^{-4}$ ≈ 0.006425 m

vii. Area = 2πrh = 2 x 3.142 x 0.006425 x 0.4 ≈ 0.01615428571 m^2

Flux = $\frac{Volume}{Area \times Time}$

Volume = 120 ml $\approx 0.12\ L$

Time = 2 min. $\approx 0.0333\ hrs$

Flux = $\frac{0.12}{0.016154285 \times 0.0333}$

Flux = 223 L/m^2 h

BIODATA OF STUDENT

Mr. Abba Mohammed Umar was born in Mubi Adamawa State, Nigeria. He obtained his school leaving certificate from Demonstration Primary School Mubi in 1986, and Senior Secondary Certificate Examination (SSCCE) in 1991. Abba Mohammed Umar is a graduate of Agricultural Engineering from University of Maiduguri, Nigeria in 1999. He acquired his Master of Engineering in Soil and Water Engineering from University of Agriculture Makurdi, Nigeria in the year 2014. In the year 2003, he worked in Adamawa State College of Agriculture as an assistant lecturer from 2003 to 2006, and later transferred his service to Federal Polytechnic Mubi in 2007 to date as a lecturer and researcher. He has served as departmental sport officer and project coordinator for period of two years. He was awarded study fellowship by Tertiary Education Trust Fund through Federal Polytechnique Mubi to pursue PhD degree in Soil and Water Engineering at Universiti Putra Malaysia. Mr. Abba Mohammed is married to Raheematu Ahmadi, and blessed with three children namely, Mas'ud, Rha'isa and Naja'atu. He enjoyed playing basket ball and travelling.

LIST OF PUBLICATIONS

Man, H.C.; **Abba, M.U;** Abdulsalam, M.; Syahidah, R. Utilization of Nano-TiO_2 as an influential additive for Complementing Separation Performance of a Hybrid PVDF-PVP Hollow Fiber: Boron removal from leachate. ***Polymers* (Basel).** 2020, 1–20. **(Q1)(Published)**

Abba, M.U; Man, H.C; Syahidah, R. Hamzah, M.H; Synthesis of Nano-Magnetite from Industrial Mill chips for the Application of Boron Removal: Characterization and Adsorption Efficacy. ***IJERPH (Q1)*** **(Published)**

Mohammed Umar Abba, Hasfalina Che Man, Raba'ah Syahidah, Aida Isma Idris, Muhammad Hazwan Hamzah 1,2, Khairul Faezah Yunos7, and Kamil Kayode Katibi1,8Novel PVDF-PVP Hollow Fibre Membrane Augmented with TiO_2 Nanoparticles: Preparation, Characterization and Applica-tion for Copper Removal from Leachate **Nanomaterials (Q1)(Published)**