TREATMENT PERFORMANCE OF HEAVY METALS IN LANDFILL LEACHATE USING *GRACILARIA CHANGII*

NITHIYA A/P ARUMUGAM

UNIVERSITI TEKNOLOGI MALAYSIA

TREATMENT PERFORMANCE OF HEAVY METALS IN LANDFILL LEACHATE USING *GRACILARIA CHANGII*

NITHIYA A/P ARUMUGAM

A thesis submitted in fulfilment of the requirements for the award of the degree of Doctor of Philosophy

Razak Faculty of Technology and Informatics
Universiti Teknologi Malaysia

OCTOBER 2021

DEDICATION

This thesis is wholeheartedly dedicated to my lovely family members, parents, siblings, husband, sister in law, mischievous niece and nephew without whom none of my success would be possible. Their endless support, words of advice and encouragement throughout the journey is priceless and expressing my gratitude for being the pillars and backbones during tough time.

ACKNOWLEDGEMENT

First and foremost, thanking God for the blessings he showered by giving me the strength and ability to bring the PhD journey to an end. Throughout this study, the journey was not easy and full of obstacles, struggles, challenges, emotional roller coaster, losses, and gains. Therefore, every effort was taken to make everything possible. This was not possible without encouragements and all sorts of support from each one in my life, including my family members, friends, and, most importantly, supervisor and co-supervisor, who made the road less bumpy.

In preparing this thesis, I was in contact with many people, researchers, academicians, and practitioners. They have contributed to my understanding and thoughts. Foremost, my deepest gratitude goes to my supervisor Prof. Ir. Ts. Dr. Shreeshivadasan Chelliapan and co-supervisor Ts. Dr. Sathiabama T. Thirugnana expertly guided me throughout the study by sharing the excitement of these years of discovery. Their passion for research always kept me occupied with my research. Their sincere and selfless support, assistance, prompt and useful advice gave me a lifetime experience that made it possible for me to work on a topic of great interest to me. They always give the right advice at the right time and be a source of motivation. It was a pleasure working with them.

Above ground, I am indebted to my family, whose value grows with age. I have always had the utmost respect for my parents Mr. Arumugam and Mrs. Saraswathy, siblings Kalidas, Jagathisan and Saravanan. Their endless support within these years of my study is the first thing to be acknowledged above all. Never once they doubted my talent and never once uttered a single negative word that would possibly discourage me in any way. My naughty and mischievous niece and nephew Taranya and Rooban always been a stressbuster whenever I was at the peak of downfalls. The understandings of my sister-in-law, Leela, on my journey is much appreciated. My husband, Mr. Navalan, taught me that it is never too late to change careers to pursue my true passion, and that context is everything. We faced marital turbulence and misunderstandings throughout this journey. We often stood at the edge of the cliff; however, we always found the courage to start it over. His understandings of my journey and trust in myself are priceless. I bestow on him a lot.

My appreciation also extends to my colleagues, whose encouragement have been precious, and their early insights enlighten my view on this research. All the discussions were stimulating. Thanks for all the fun we had in the last few years. Not forgetting the sleepless nights, we were working together before deadlines. The very diverse and exciting colleagues stimulated and enjoyable atmosphere. A particular word of thanks to my laboratory assistant Mr.Azmi Bin Abu Bakar, for his quick guidance and support while working in the laboratory. He has been more than a friend in giving advice and always made himself available whenever I need a helping hand at the laboratory. He always prepares requested materials in advance to avoid any possible obstacles. The completion of this undertaking could not have been possible without the participation, assistance and support of so many people whose names may not all be enumerated. Their direct and indirect contributions in any manners are sincerely appreciated and gratefully acknowledged. I am also indebted to Universiti Teknologi Malaysia (UTM) to further my PhD and conduct research on my field of interests.

ABSTRACT

Leachate is a serious environmental issue due to its highly toxic contents, and it is being treated using several methods such as biological, chemical, and physical processes or the combination of these processes. However, the treated leachate somehow still needs to be refined in order to achieve the allowable standard set by the authority before it can be discharged into the environment. In this study, the leachate from Jeram Sanitary Landfill was subjected to the physico-chemical treatment method using a *Gracilaria changii* seaweed species to remove the heavy metals. The specific objectives of this study include the preparation and characterisation of *G. changii* biosorbent, the heavy metal removals (such as Fe^{2+}, Cr^{6+}, As^{5+}, Ni^{2+} and Cd^{2+}) performance assessments in a batch study, the investigation of heavy metal removals using a continuous fixed-bed column, and the evaluation of the adsorption kinetics and isotherms of heavy metals by *G. changii*. The batch study's initial investigation showed that the optimal condition for treating landfill leachate is at the pH of 5 with the adsorbent dosage of 10 g, 50 rpm and 30 min contact time. Around 97.5%, 70.9%, 42.43%, 98% and 40% of Fe^{2+}, Cr^{6+}, As^{5+}, Cd^{2+} and Ni^{2+} maximum removals were achieved respectively at 30 min, 10 g dosage, and heavy metal concentration of 100 mg/L with optimum pH and rpm. The adsorption behaviours of *G. changii* biosorbent were analysed using Field-Emission Scanning Electron Microscope-Energy Dispersive X-ray (FESEM-EDX) and Fourier Transform Infra-Red (FTIR) spectroscopy. The results showed visible evidence of the binding microelement ions on the surfaces of the biosorbent, and also demonstrated that the carboxyl and hydroxyl groups were found to be efficient for adsorbing the heavy metals from the landfill leachate. The investigation over the treatment performance of *G. changii* in a continuous fixed-bed column with leachate pH 6.5 and 3.5 mL/min flowrate using 50% fine silicone sand and 50% biosorbent indicated that the influence of fine silicone sand removal efficiency is negligible and proved via a controlled study that recorded Fe^{2+}, Cr^{6+}, As^{5+}, Cd^{2+} and Ni^{2+} removals were 1%, 1.33%, 1.5%, 0.17% and 0.5%, respectively. The 1:1 packing ratio achieved the optimum removal at 24th hours, with Fe^{2+}, Cr^{6+}, As^{5+}, Cd^{2+} and Ni^{2+} removals were 99.5%, 99.93%, 99.2%, 99.97% and 99.97%, respectively with an initial concentration of each heavy metal fixed at 60 mg/L. The kinetic analysis conducted over the jar test results concluded that the adsorption obeys pseudo-second order. Thus, the occupation rate of adsorption is proportional to the square of the vacant active sites numbers on the biosorbent. Meanwhile, the isotherm analysis demonstrated a higher correlation coefficient for the Freundlich isotherm, thus the biosorption was shown to be heterogeneous, multilayer and occurred on the surface. The results also established that *G. changii* biosorbent has active sites with different energies. In addition, the regeneration studies showed that the *G. changii* can be regenerated more than once, with as high as 83% of desorption percentage at 5th cycle, which verified that the regeneration of biosorbent after recovery was successful. Therefore, it can be concluded that the *G. changii* biosorbent successfully removed heavy metals from the leachate solution and is potentially useful for the wastewater treatment industry.

ABSTRAK

Bahan larut lesap sisa pepejal menjadi isu alam sekitar serius kerana kandungan toksiknya yang tinggi dan ianya dirawat menggunakan beberapa kaedah seperti biologi, kimia dan fizikal atau gabungan kaedah-kaedah ini. Walaubagaimanapun, bahan larut lesap sisa pepejal yang telah dirawat masih memerlukan rawatan tambahan untuk mencapai piawai yang dibenarkan oleh pihak berkuasa sebelum ianya dibuang ke persekitaran. Dalam kajian ini, bahan larut lesap sisa pepejal dari Tapak Pelupusan Sanitari Jeram dirawat secara kimiafizik menggunakan spesies rumpai laut *Gracilaria changii* bagi penyingkiran logam berat. Objektif khusus kajian ini termasuklah penyediaan dan pencirian biosorben *G. changii*, penilaian prestasi terhadap penyingkiran logam berat (seperti Fe^{2+}, Cr^{6+}, As^{5+}, Ni^{2+} dan Cd^{2+}) melalui kajian kelompok, penyingkiran logam berat menggunakan turus lapisan tetap berterusan, dan penilaian kinetik penjerapan dan isotherma bagi logam berat oleh *G. changii*. Siasatan awal kajian kelompok menunjukkan keadaan yang paling optimum untuk merawat bahan larut lesap sisa pepejal adalah pada pH 5 dengan dos bahan penjerap 10 g, 50 rpm dan masa kontak 30 min. Penyingkiran maksimum sebanyak 97.5%, 70.9%, 42.43%, 98% dan 40% dicapai untuk Fe^{2+}, Cr^{6+}, As^{5+}, Cd^{2+} dan Ni^{2+} pada 30 min, dos 10 g, dan kepekatan logam berat 100 mg/L pada pH dan rpm yang optimum. Penjerapan biosorben *G. changii* dianalisis menggunakan spektroskopi *Field Emission Scanning Electron Microscope-Energy Dispersive X-ray* (FESEM-EDX) dan *Fourier Transform Infra-Red* (FTIR). Hasilnya jelas membuktikan terdapat ion-ion mikroelemen yang terikat pada permukaan biosorben dan menunjukkan kumpulan karboksil dan hidroksil berkesan dalam penjerapan logam berat daripada bahan larut lesap sisa pepejal di tapak pelupusan. Siasatan ke atas prestasi rawatan *G. changii* di dalam turus lapisan tetap berterusan dengan pH 6.5 dan kadar aliran 3.5 mL/min menggunakan 50% pasir halus silikon dan 50% biosorben menunjukkan pengaruh kecekapan penyingkiran bagi pasir halus silikon logam adalah diabaikan dan dibuktikan melalui kajian kawalan yang mencatatkan penyingkiran sebanyak 1%, 1.33%, 1.5%, 0.17% dan 0.5% bagi Fe^{2+}, Cr^{6+}, As^{5+}, Cd^{2+} dan Ni^{2+}. Nisbah padatan 1:1 mencapai penyingkiran optimum sebanyak 99.5%, 99.93%, 99.2%, 99.97% dan 99.97% untuk Fe^{2+}, Cr^{6+}, As^{5+}, Cd^{2+} dan Ni^{2+} pada jam ke-24 dengan kepekatan logam berat 60 mg/L. Analisis kinetik terhadap ujian balang menunjukkan penjerapan mematuhi urutan pseudo-kedua. Oleh itu, penjerapan adalah berkadaran dengan segiempat bilangan tapak-tapak aktif yang kosong di atas biosorben. Di samping itu, analisis isoterma menunjukkan pekali korelasi yang lebih tinggi untuk isoterma Freundlich, maka biosorpsi adalah heterogen, berlapis-lapis dan berlaku di tahap permukaan. Hasil kajian juga membuktikan biosorben *G. changii* mempunyai tapak-tapak aktif dengan tenaga yang berbeza. Tambahan pula, *G. changii* boleh dijana semula lebih dari sekali, dengan peratusan desorpsi setinggi 83% pada kitaran yang ke-5 dengan mengesahkan penjanaan semula yang berjaya selepas pemulihan. Oleh itu, boleh disimpulkan bahawa biosorben *G. changii* berjaya menyingkirkan logam berat daripada larutan bahan larut lesap sisa pepejal dan ianya berpotensi untuk digunakan dalam rawatan air sisa industri.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AAS	-	Atomic Absorption Spectrometer
AC	-	Activated Carbon
ADMI	-	American Dye Manufactures Institute
ASP	-	Activated Sludge Processes
BOD	-	Biological Oxygen Demand
COD	-	Chemical Oxygen Demand
DOE	-	Department of Environment
EDX	-	Energy Dispersive X-ray
EPA	-	Environmental Protection Agency
FESEM	-	Field-Emission Scanning Electron Microscope
FTIR	-	Fourier Transform Infrared Spectroscopy
GAC	-	Granular Activated Carbon
HDPE	-	High-Density Polyethylene
MF	-	Microfiltration
MSW	-	Municipal Solid Waste
MSWM	-	Municipal Solid Waste Management
NF	-	Nanofiltration
NSWMD	-	National Solid Waste Management Department
PAC	-	Polyaluminium Chloride
PAC	-	Powdered Activated Carbon
PZ	-	Powdered ZELIAC
RBC	-	Rotating Biological Contactor
RO	-	Reverse Osmosis
SBR	-	Sequencing batch reactor
SHL	-	Super Hybrid Lens
SS	-	Suspended Solids
TF	-	Trickling Filters
TKN	-	Total Kjeldahl Nitrogen
UF	-	Ultrafiltration
UN	-	United Nation

LIST OF SYMBOLS

°C	-	Degree Celsius
%	-	Percentage
q_t	-	Quantity of adsorption per unit mass of adsorbent
C_i	-	Initial concentrations of metal ions
C_f	-	Equilibrium or unadsorbed concentrations of metal ions
C_e	-	Equilibrium concentration
V	-	Volume
m	-	Mass
q_e	-	Quantity of adsorption per unit mass of adsorbent
q_m	-	Maximum amount of metal ions
K_L	-	Langmuir constant
R_L	-	Dimensionless constant separation factor
K_F	-	Freundlich constants related to adsorption capacity
n	-	Freundlich constants related to adsorption intensity
t	-	Time
hr	-	Hour
k_1	-	Rate constant of pseudo-first order adsorption
k_2	-	Rate constant of pseudo-second order adsorption
b	-	Langmuir constant

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Research Background

The world's population is increasing daily and is projected to hit 8.5 billion by 2030, thus propelling the necessary urge towards urbanisation (Hongbo, 2015). The rate of urban waste being produced is faster than the rate of urbanisation, and this signifies mankind's growing affluence. As the global population increases, the generation of municipal solid waste (MSW) has also increased, and these wastes acquired alarming space dimensions globally. Approximately 1.3 billion metric tonnes of MSW were generated globally in 2016 (Kawai and Tasaki, 2016) and the amounts are expected to rise to about 2.2 billion by 2025 (Hoornweg and Bhada-Tata, 2012). The factors influencing the MSW generation are economic development, industrialisation, and public practices of the region (Fazeli, Bakhtvar, Jahanshaloo, Sidik & Bayat, 2016), urbanisation and changing consumption patterns (Adhikari, Dahal & Khanal, 2014).

The disposal of MSW can be divided into six stages such as open dumping, sanitary landfills (preliminary recycling), incineration without energy recovery (1st generation including sanitary landfills and more recycling), incineration with energy recovery (2nd and 3rd generation), advanced thermal treatment (4th generation involving incineration with energy recovery), and lastly, advanced technology for converting wastes into energy (Edris, Alhamed & Alzahrani, 2014). Most of the developing countries are still at stage 2, while most advanced countries are reaching stage 4 or 5 of the processes (Elagroudy, Warith & Zayat, 2016). The statistics have shown that the projected world population of 11 billion people in 2100 produce 33,000 metric tonnes of MSW per day (Hara, 2020; Ng and Iacovidou, 2020). This immense increase in the number is mostly due to the rising lifestyle, urbanisation, changes in food habits and high consumptions of packed food (Khan, Kumar & Samadder, 2016).

Although the energy production through MSW's utilisation has been globally implemented for many decades, Malaysia is still highly depending on the landfills method for MSW management, as Malaysia is still at the second stage of MSW's treatment and disposal process (Tan, Ho, Hashim, Lee, Taib & Ho, 2015). Currently, there are almost 300 solid waste disposal sites in Malaysia (NSWMD, 2015), but only 14 out of those are having the operating sanitary landfills status (Jalil, 2016).

The MSW disposals to landfills method typically produce leachate. Leachate is defined as the aqueous effluent generated as a by-product of rainwater that percolates through wastes, biochemical processes and the inherent wastes water contents (Li, Wang, Yue, Tao, Yang, Zhou & Chen, 2017). One metric ton of MSW in humid landfill was reported to generate 0.148 m^3 of leachate (Abunama, Othman & Nilam, 2021). In Malaysia, only limited data were available on the leachate amount generated from the Malaysian landfills (Aziz, Adlan, Amilin, Yusoff, Ramly & Umar, 2012).

The factors such as moisture content, site hydrology, landfill age, climatic conditions, and the degree of waste stabilisation determine the qualities and quantities of leachate generated (Adhikari et al., 2014). Highly concentrated leachate is produced mainly from the traditional (unscientific) collection, separation, and disposal activities of MSW (Naveen, Mahapatra, Sitharam, Sivapullaiah & Ramachandra, 2017). Consequently, the continuous generation of leachate leads to potential long-term environmental risk. Generally, the leachate contains various toxic compounds at low concentrations, high amounts of colour components, ammonia nitrogen, heavy metals, organic and inorganic compounds (Patel and Desai, 2014; Dan, Oka, Fujii, Soda, Ishigaki, Machimura & Ike, 2017). Heavy metals found in leachate are the most toxic environmental pollutant and are thus given great attention due to their harmful nature, especially when the levels exceeded the regulatory standards (Adamu, Nganje & Edet, 2015).

The heavy metals buildup in soil and groundwater is a growing concern, and this buildup is due to the different types/sources of wastes (Raisi, Sulaiman, Suliman & Abdallah, 2014). The sources such as used batteries, electronic wastes and paint wastes contribute to the accumulation of heavy metals pollutants in the leachate (Aderemi, Oriaku, Adewumi & Otitoloju, 2011). Chromium (Cr), Nickel (Ni), Copper (Cu), Arsenic (As), Cadmium (Cd), Mercury (Hg) and Lead (Pb) are the globally alarming and toxic heavy metals (Islam, Ahmed, Raknuzzaman, Mamun & Islam, 2015). These toxic pollutants threaten living organisms, even at a minute amount (Storelli, Storelli, Addabbo, Marano, Bruno & Marcotrigiano, 2005). Pb is highly toxic to the kidney, nervous system and reproductive system (Gautam, Sharma, Mahiya & Chattopadhyaya, 2014), whereas Hg is a neurotoxin that inhibits the enzymatic activities for normal neurotransmission and causes structural damages (Solomon, 2008). Environmental As exposure may also cause health defects and leads to tumour or cancer formation (Tsuji, Perez, Garry & Alexander, 2014; Cohen, Arnold, Beck, Lewis & Eldan, 2013). As is transported through the water bodies into the environment, absorbed from soils to plants, and can build up in many food crops and aquatic plants, threatening human health through contaminated food consumption. Moreover, studies have proven that the rice consumed may be the possible primary source of inorganic As (Carotenuto, Lofrano & Sharma, 2015). The environmental exposure of Cd is prompted by human activities such as the manufacturing of cement and construction materials, welding alloys, foundries, manufacturing steel and alloys, electroplating industry, lamps, mines, urban waste and industrial waste incineration, coal ash, tanneries, fertilisers and wood preservatives (Gutterres and Mella, 2015). Each type of heavy metals that exist in the leachate poses many risks to the environment and humans.

Many leachate treatment methods have been adopted in practice, including biological (activated sludge, aerobic and anaerobic stabilization ponds and biological filters), physicochemical (coagulation/flocculation, adsorption, chemical precipitation, stripping, chemical oxidation, ion exchange and electrochemical treatment), membrane filtration (microfiltration/ultrafiltration, nanofiltration and reverse osmosis), advanced oxidative processes (Fenton and ozonation) and natural systems (wetlands) (Kamaruddin, Yusoff, Aziz & Hung, 2015; Lebron, Moreira, Brasil, Silva, Santos, Lange & Amaral, 2021). The biological leachate treatment is the most commonly used method for removing the leachate bulk containing high BOD level due to the simplicity, reliability and economic effectiveness of the method (Peng, 2017). The biological leachate treatment can be further divided into the aerobic and anaerobic systems. Under aerobic conditions, the microorganism biodegrades organic compounds to carbon dioxide, while under the anaerobic conditions (Bajpai, 2017), the organic compounds are biodegraded to biogas (a mixture of CO_2 and CH_4) and biomass. Due to the limitations such as sludge bulking in the conventional aerobic system that disturb the leachate treatment, the anaerobic treatment is now becoming a possible substitute due to its general advantages over the aerobic systems. However, due to the high ammoniacal nitrogen content with the increase in landfill age, the biological treatment could still become ineffective. Even though the biological leachate treatment systems are being primarily used, the integration of physicochemical techniques are being adopted as co-treatment to give better leachate treatment performances and reduce the adverse effects on the environment (Naveen et al., 2017). The commonly used physicochemical techniques in leachate treatment include membrane technology, coagulation, flocculation and adsorption (Peng, 2017). However, the techniques or coupling choices exclusively depends on the leachate composition.

The constant tropical weather with clear coastal waters is suitable for seaweed growth (Sasidharan, Darah & JainNoordin, 2010). The *Gracilaria changii* is able to grow abundantly in hot and humid equatorial countries, such as Malaysia (Phang, Shaharuddin, Noraishah & Sasekumar, 1996). The *G. changii* is considered food and has other edible properties, but the algae's economic importance is beginning to gain more attention, especially in the pharmaceuticals industry (Chan and Matanjun, 2017). Seaweed is a fast-growing organism and due to its varying characteristics, is used for multiple reasons, including as a balancer in mitigating eutrophication for nutrient management, as bioremediation in the ecosystem, as seaweed extract and as fertilisers and fresh food (Safinaz and Ragaa, 2013; Holdt and Edwards, 2014; Selvam and Sivakumar, 2014; Kim, Yarish, Hwang, Park & Kim, 2017; Lee, Lim, Leow, Namasivayam, Abdullah & Ho, 2017). Therefore, seaweed with these essential criteria has stimulated researches to be conducted abundantly, specifically on the varying seaweeds types to access the adsorbent capability in removing heavy metals from different wastewaters sources, including the landfill leachate, synthetic and simulated wastewater (Selvam, Chelliapan, Din, Shahperi & Aris, 2016; Barquilha, Cossich, Tavares & Silva, 2017; Cardoso, Costa, Nishikawa, Silva & Vieira, 2017; Mahmood, Zahra, Iqbal, Raza & Nasir, 2017). The studies showed that the seaweed in its raw and pre-treated form is able to absorb the heavy metals in synthetic wastewater and metallurgy wastewater (Edris et al., 2014; Ungureanu, Santos, Boaventura & Botelho, 2015; Barquilha et al., 2017; Vafajoo, Cheraghi, Dabbagh & McKay, 2018).

1.2 Problem Statement

The treatment of leachate is necessary to minimise the heavy metals contents that constitute potential risks to the natural ecosystem and may lead to carcinogenic effects on living species (Zhao, Gao, Yue, Liu & Shon, 2016). The leachate treatment methods currently being practised include aerobic-anaerobic biological reactions and physical and chemical reactions (Wiszniowski, Robert, Surmacz-Gorska, Miksch & Weber, 2006; Amor, Torres-Socias, Peres, Maldonado, Oller, Malato & Lucas, 2015). Still, these heavy metals could not be removed effectively during the treatment processes and, therefore, could not be discharged into the watercourses due to the issues such as landfills ageing and the complex nature of leachate (Amor et al., 2015).

The adsorption technique using activated carbon receives great interests and has been widely used at the final purification stage of leachate treatment. The activated carbon exhibits superior properties such as having a larger surface area, high adsorption capacity and better thermal stability (Kamaruddin et al., 2015). Mojiri, Aziz, Zaman, Aziz & Zahed (2016) studied the powdered ZELIAC removal efficiencies for Iron (Fe), Manganese (Mn), Ni and Cd and showed that the removal percentages of 79.57%, 73.38%, 79.29% and 76.96%, respectively. The powdered ZELIAC consists of portland cement, limestone, rice husk ash, activated carbon and zeolite and its usage improves the Sequencing Batch Reactor (SBR) during the combined treatment of urban wastewater and landfill leachate. There are studies that used chemically activated carbon made from lignocellulosic wastes (sawdust) (Nayak, Bhushan, Gupta & Sharma, 2017), clinoptilolite zeolite (Zanin, Scapinello, Oliveira, Rambo, Franscescon, Freitas, Mello, Fiori, Oliveira & Magro, 2017) and iron oxide-coated gravel for removing heavy metals found in leachate (Sizirici and Yildiz, 2017). Activated carbon successfully removed recalcitrant pollutants after biological treatment. However, the contaminants such as heavy metals (Mohammad-pajooh, Weichgrebe & Cuff, 2017) could not be removed effectively. Furthermore, some industry players are looking for activated carbon alternatives, as the activated carbon is acknowledged as costly and is complex to be regenerated (Ariffin, Abdullah, Zainol, Murshed, Hariz-Zain, Faris & Bayuaji, 2017; Keng, Lee, Ha, Hung & Ong, 2014).

New approaches are vital to develop sustainable treatment methods, as most of the wastewater treatment processes, especially those based on conventional biological methods, are inefficient for heavy metals removal (Das, Patel, De & DasGupta, 2006). Other adsorbents types, such as coal bottom ash, clay minerals, synthetic resins, and many types of naturally found adsorbents, are being studied for heavy metals removal from wastewater. The removal efficiencies of these adsorbents are as low as 14% (Kadir, Mustafa, Bakri, Sandu, Noor, Lisanah, Latif & Hussin, 2014) to as high as 100% (Erabee, Ahsan, Jose, Aziz, Ng, Idrus & Daud, 2017). However, efforts to find more alternatives are still being performed. Therefore, this research aims to introduce naturally found *G. changii* as a potential biosorbent for heavy metal removal from raw landfill leachate. *G. changii* is a macroalga and it is a red seaweed that lives underwater with huge species biodiversity in Asia, especially in Malaysia. Although many other seaweed species are being widely used for research purposes, the *G. changii* species is yet to be explored using real landfill leachate for wastewater treatment purposes.

Some studies had reported that the heavy metals leached from the Jeram Sanitary Landfill are a dominant issue due to the sources of the waste from various industries (Ishak, Mohamad, Soo & Hamid, 2016). Those heavy metals contents are above the allowable limit as determined by the Standard B requirement established by the Department of Environment (Kasmuri and Tarmizi, 2018). Currently, activated carbon has been used in the physical processing stage of the reported landfill. However, only around 85% of maximum removal was observed when the hybrid activated carbon is used (Erabee, 2017). The highest removal of 86% was reported by using Zinc to treat the leachate from the Jeram Sanitary Landfill (Erabee, Ahsan, Jose, Aziz, Ng, Idrus & Daud, 2018). Although these removal efficiencies are numerically high, the landfill operators still think that the heavy metals contents are way high to be safely discharged into water bodies, as these levels could still be toxically threatening to the environment and ecosystem. Therefore, the current research aims to replace the existing activated carbon in the treatment system with *G. changii* biosorbent as an alternative.

This research was conducted to replace the activated carbon at the final purification stage of the treatment system with *G. changii* biosorbent to polish the treated leachate further to remove any heavy metals that remain after the biological and chemical treatment. However, the sample for this study was taken from the raw leachate that contains a high amount of heavy metals. This is because the amount of heavy metals after the biological and chemical treatments are insufficient or very low in concentration during the sampling period. If the *G. changii* can remove the relatively high level of heavy metals in raw leachate, thus it can be replaced at any part of the treatment system.

1.3 Research Questions

The research questions of this study are listed as follows:

1. What are the characteristics of *G. changii* adsorbent?
2. What is the leachate heavy metals removal efficiency of the *G. changii* adsorbent based on the batch analysis?
3. What is the leachate heavy metals removal efficiency of the *G. changii* adsorbent based on the continuous fixed-bed column process?
4. What are the heavy metals adsorption kinetics and isotherm values of the *G. changii* adsorbent?

1.4 Research Objectives

This research aims to treat the landfill leachate containing heavy metals with naturally occurring *G. changii* during the polishing stage of leachate treatment. The specific objectives of this research are:

1. To prepare and characterise the properties of *G. changii* adsorbent.

2. To assess landfill leachate heavy metals removal performances using the *G. changii* adsorbent in a batch study.

3. To investigate landfill leachate heavy metals removal performances using the *G. changii* adsorbent in a continuous fixed-bed column.

4. To evaluate the adsorption kinetics and isotherm of heavy metals by the *G. changii* adsorbent.

1.5 Scope of Research

The landfill leachate used in this study was collected from the Jeram Sanitary Landfill located in Selangor. The total required amount of leachate samples was collected only once, and the frequent sampling method was not practised so that the continuity of characterisation study can be maintained throughout the research. The Fe^{2+}, Cr^{6+}, As^{5+}, Cd^{2+} and Ni^{2+} heavy metals were selected as the targeted heavy metals for this research since these metals are the main concerns of landfill operators and are difficult to remove from the current treatment systems. Therefore, current study used raw leachate spiked with heavy metals concentrations in order to study the performance of treatment.

The seaweed used in this research was the *G. changii* species collected from the cultivating pond located near to the seaside area in Kota Kuala Muda, Kedah. The *G. changii* was characterized based on the size and morphological components. The *G. changii* biosorbent was used to investigate the leachate heavy metals removal by using the batch study, as well as by using the continuous fixed-bed column developed.

The continuous fixed-bed column testing was carried out at room temperature (25^0C) and was kept constant throughout the research. The heavy metals adsorption kinetics and isotherm analysis were evaluated. The pseudo-first-order and pseudo-second-order models were used for the adsorption kinetics study, while the Langmuir, Freundlich and Dubinin-Radushkevich models were used for the isotherm study to describe the best fit model for the leachate treatment. These models explained the adsorption mechanisms, the conducive of adsorption processes and the adsorbate-adsorbent affinity. Lastly, the regeneration studies conducted on the *G. changii* via adsorption/desorption cycles to identify the ability to regenerate.

The chemical and physical analysis for this research was conducted at room temperature in the laboratory within the Universiti Teknologi Malaysia (UTM) premises. The majority of the research experiments were carried out in the Environmental Engineering Laboratory, while the analytical studies were conducted in the Analytical Laboratory of the Malaysia-Japan International Institute of Technology (MJIIT), UTM.

1.6 Significance of Research

The newly introduced and incorporated *G. changii* biosorbent is developed for landfill leachate treatment containing heavy metals and is projected to be a promising method for wastewater treatment. Firstly, the development and production processes of *G. changii* biosorbent do not involve the usage of any chemicals. Thus, the usage of seaweed powder in removing heavy metals from the landfill leachate is a clean and eco-friendly method. The *G. changii* biosorbent contains beneficial criteria that it can be succeeded as an alternative platform to the existing leachate treatment method and aims to become the main green solution for wastewater containing heavy metals.

Secondly, there are plenty of seaweed species that has been explored so far for wastewater treatment. However, the biosorbent explicitly developed from the *G. changii* species has yet to be tested. Therefore, this study is an effort to introduce a new biosorbent for the industry. Thirdly, most of the research on seaweed-based biosorbent used synthetic and simulated wastewater instead of raw wastewater. Furthermore, very few studies are being conducted using real landfill leachate and the seaweed biosorbent to remove heavy metals over the decades. Hence, this is an attempt using raw landfill leachate and the *G. changii* biosorbent for a detailed study.

Moreover, in this study the performance of *G. changii* in removing more heavy metals (five) from landfill leachate being tested. Besides that, this performance of G. *changii* in batch study being evaluated using commonly and frequently used two different kinetic models and three different isotherm models for better understanding of the mechanisms involved. Researchers commonly uses two isotherms to compare their experimental data, however, in this study three different isotherms are being used to evaluate the better fit of jar test results. The idea of using naturally (untreated) and wildly grown *G. changii* as an alternative adsorbent could be an ideal and effective method that can assist the solid waste industry or the leachate treating companies in the future.

1.7 Overview of the Thesis

This thesis comprises five main chapters. Firstly, Chapter 1 sets the study background, including the problem statement, research questions, research objectives, scopes, and the study's significance. Then, Chapter 2 discusses the literature reviews on the related research by including the fundamentals of municipal solid waste and landfill industry in Malaysia, followed by an overview of the landfill procession, the generation of leachate and its characterisation, the existing treatment of leachate, the sources of heavy metals content in leachate and finally the toxicity towards living forms. Next, the literature review focuses on the topics related to *G. changii* by providing the overview of seaweed classification, the industrial application of seaweed, the background of *G. changii* followed by the review on a continuous fixed-bed column in wastewater treatment as well as the discussion on the adsorption kinetics and isotherm models. Meanwhile, Chapter 3 provides the descriptions of methodology, apparatus and experimental equipment used throughout this research. This chapter consists of the leachate characterisation protocol, the formulation of leachate spiked with heavy metals concentration, the characterisation of *G. changii*, the equipment involved in basic and advanced characterisation, jar test procedure, optimisation experiments, the design of continuous fixed-bed column, and the methods of kinetic and isotherm. On top of that, the results obtained from experiments are discussed thoroughly in Chapter 4. Chapter 5 holds the conclusion from the current research and provides recommendations for future research scopes. Finally, this thesis is ended with a list of publications, references, and appendices.

REFERENCES

Abdelnaeim, M. Y., Sherif, I. Y. E., Attia, A. A., Fathy, N. A. and El-Shahat, M. F. (2016) 'Impact of chemical activation on the adsorption performance of common reed towards Cu(II) and Cd(II)', *International Journal of Mineral Processing*, 157, 80–88.

Abdolali, A., Ngo, H. H., Guo, W., Zhou, J. L., Zhang, J., Liang, S., Chang, S. W., Nguyen, D. D. and Liu, Y. (2017) 'Application of a breakthrough biosorbent for removing heavy metals from synthetic and real wastewaters in a lab-scale continuous fixed-bed column', *Bioresource Technology*, 229, 78–87.

Abomohra, A. E.-F. and Almutairi, A. W. (2020) 'A close-loop integrated approach for microalgae cultivation and efficient utilization of agar-free seaweed residues for enhanced biofuel recovery', *Bioresource Technology*, 317, 1–11.

Abtahi, M., Mesdaghinia, A., Saeedi, R. and Nazmara, S. (2013) 'Biosorption of As (III) and As (V) from aqueous solutions by brown macroalga *Colpomenia sinuosa* biomass: Kinetic and equilibrium studies', *Desalination and Water Treatment*, 51(16–18), 3224–3232.

Abunama, T., Othman, F. and Nilam, T. I. T. (2021) 'Comparison of landfill leachate generation and pollution potentials in humid and semi-arid climates', *International Journal of Environment and Waste Management*, 27(1), 79–92.

Adamu, C. I., Nganje, T. N. and Edet, A. (2015) 'Heavy metal contamination and health risk assessment associated with abandoned barite mines in Cross River State, Southeastern Nigeria', *Environmental Nanotechnology, Monitoring & Management*, 3, 10–21.

Adekola, F. A., Hodonou, D. S. S. and Adegoke, H. I. (2016) 'Thermodynamic and kinetic studies of biosorption of iron and manganese from aqueous medium using rice husk ash', *Applied Water Science*, 6, 319–330.

Aderemi, A. O., Oriaku, A. V., Adewumi, G. A. and Otitoloju, A. A. (2011) 'Assessment of groundwater contamination by leachate near a municipal solid waste landfill', *African Journal of Environmental Science and Technology*, 5(11), 933–940.

Adharini, R. I., Suyono, E. A., Suadi, Jayanti, A. D. and Setyawan, A. R. (2019) 'A comparison of nutritional values of *Kappaphycus alvarezii*, *Kappaphycus striatum*, and *Kappaphycus spinosum* from the farming sites in Gorontalo Province, Sulawesi, Indonesia', *Journal of Applied Phycology*, 31, 725–730.

Adhikari, B., Dahal, K. R. and Khanal, S. N. (2014) 'A review of factors affecting the composition of municipal solid waste landfill leachate', *International Journal of Engineering Science and Innovative Technology*, 3(5), 273–281.

Agamuthu, P. and Fauziah, S. H. (2011) 'Challenges and issues in moving towards sustainable landfilling in a transitory country - Malaysia', *Waste Management and Research*, 29(1), 13–19.

Agbugui, P. A. and Nwaedozie, J. M. (2015) 'Adsorption of heavy metals from simulated landfill leachates unto composite mix of agricultural solid wastes', *IOSR Journal of Applied Chemistry*, 8(2, Version I), 49–54.

Ahmed, M. J., Okoye, P. U., Hummadi, E. H. and Hameed, B. H. (2019) 'High-performance porous biochar from the pyrolysis of natural and renewable seaweed (*Gelidiella acerosa*) and its application for the adsorption of methylene blue', *Bioresource Technology*, 278, 159–164.

Akbari, M., Hallajisani, A., Keshtkar, A. R., Shahbeig, H. and Ghorbanian, S. A. (2015) 'Equilibrium and kinetic study and modeling of Cu (II) and Co (II) synergistic biosorption from Cu (II)-Co (II) single and binary mixtures on brown algae *C. indica*', *Journal of Environmental Chemical Engineering*, 3(1), 140–149.

Akunwa, N. K., Muhammad, M. N. and Akunna, J. C. (2014) 'Treatment of metal-contaminated wastewater: A comparison of low-cost biosorbents', *Journal of Environmental Management*, 146, 517–523.

Al-Asgah, N. A., Younis, E.-S. M., Abdel-Warith, A.-W. A. and Shamlol, F. S. (2016) 'Evaluation of red seaweed *Gracilaria arcuata* as dietary ingredient in African catfish, *Clarias gariepinus*', *Saudi Journal of Biological Sciences*, 23(2), 205–210.

Al-Jabari, M. (2016) 'Kinetic models for adsorption on mineral particles comparison between langmuir kinetics and mass transfer', *Environmental Technology and Innovation*, 6, 27–37.

Al-Qahtani, K. M. (2016) 'Water purification using different waste fruit cortexes for the removal of heavy metals', *Journal of Taibah University for Science*, 10(5), 700–708.

Al-Senani, G. M. and Al-Fawzan, F. F. (2018) 'Adsorption study of heavy metal ions from aqueous solution by nanoparticle of wild herbs', *Egyptian Journal of Aquatic Research*, 44(3), 187–194.

Alberti, G., Amendola, V., Pesavento, M. and Biesuz, R. (2012) 'Beyond the synthesis of novel solid phases: Review on modelling of sorption phenomena', *Coordination Chemistry Reviews*, 256(1–2), 28–45.

Ali, M. K. M., Sulaiman, J., Yasir, S. M. and Ruslan, M. H. (2015) 'The effectiveness of sauna technique on the drying period and kinetics of seaweed *Kappaphycus alvarezii* using solar drier', *Journal of Agricultural, Food, and Environmental Sciences*, 86–95.

Alrozi, R., Zubir, N. A., Kamaruddin, M. A., Yusof, S. N. F. M. and Yusoff, M. S. (2017) Removal of organic fractions from landfill leachate by *Casuarina equisetifolia* activated carbon: Characteristics and adsorption mechanisms. *AIP Conference Proceedings*. September. 020139-1-020139–7. doi: 10.1063/1.5002333.

Alslaibi, T. M., Abustan, I., Ahmad, M. A. and Foul, A. A. (2014) 'Comparison of activated carbon prepared from olive stones by microwave and conventional heating for Iron (II), Lead (II), and Copper (II) removal from synthetic wastewater', *Environmental Progress & Sustainable Energy*, 33(4), 1074–1085. doi: 10.1002/ep.11877.

Arabi, S. and Lugowski, A. (2015). Lessons learned from successful applications of biological landfill leachate treatment. *Environmental Science & Engineering Magazine*, January/February, 1–5.

Ariffin, N., Abdullah, M. M. A. B., Zainol, M. R. R. M. A., Murshed, M. F., Hariz-Zain, Faris, M. A. and Bayuaji, R. (2017) Review on adsorption of heavy metal in wastewater by using geopolymer. *MATEC Web of Conferences*, 97, 01023-1-01023–8.

Arumugam, N., Chelliapan, S., Rahman, Z. A., Thirugnana, S. T., Ahmad, I., Krishnan, S. and Din, M. F. M. (2019) *Gracilaria changii*: Seaweed adding value to heavy metals removal from leachate. *International Conference on*

Environmental Sustainability and Resource Security. 5 & 6 November. Kuala Lumpur, Malaysia, 183–188.

Arumugam, N., Chelliapan, S., Thirugnana, S. T. and Jasni, A. B. (2020) 'Optimisation of heavy metals uptake from leachate using red seaweed *Gracilaria changii*', *Journal of Environmental Treatment Techniques*, 8(3), 1089–1092.

Aryal, M. and Liakopoulou-Kyriakides, M. (2015) 'Bioremoval of heavy metals by bacterial biomass', *Environmental Monitoring and Assessment*, 187(4173), 1–26.

Ayala, J. and Fernández, B. (2016) 'A case study of landfill leachate using coal bottom ash for the removal of Cd^{2+}, Zn^{2+} and Ni^{2+}', *Metals*, 6(12), 300–314.

Aziz, H. A., Adlan, M. N., Amilin, K., Yusoff, M. S., Ramly, N. H. and Umar, M. (2012) 'Quantification of leachate generation rate from a semi-aerobic landfill in Malaysia', *Environmental Engineering and Management Journal*, 11(9), 1581–1585.

Aziz, H. A., Yii, Y. C., Syed, Z. S. F. F., Ramli, S. F. and Akinbile, C. O. (2018) 'Effects of using *Tamarindus indica* seeds as a natural coagulant aid in landfill leachate treatment', *Global NEST Journal*, 20(2), 373–380.

Aziz, H. A., Yusoff, M. S., Adlan, M. N., Adnan, N. H. and Alias, S. (2004) 'Physico-chemical removal of iron from semi-aerobic landfill leachate by limestone filter', *Waste Management*, 24, 353–358.

Aziz, S. Q., Aziz, H. A., Bashir, M. J. K. and Mojiri, A. (2015) 'Assessment of various tropical municipal landfill leachate characteristics and treatment opportunities', *Global NEST Journal*, 17(3), 439–450.

Aziz, S. Q., Aziz, H. A., Yusoff, M. S., Mojiri, A. and Amr, S. S. A. (2012) 'Adsorption isotherms in landfill leachate treatment using powdered activated carbon augmented sequencing batch reactor technique: Statistical analysis by Response Surface Methodology', *International Journal of Chemical Reactor Engineering*, 10(1), 1–22.

Babu, D. J., Sumalatha, B., Venkateswarulu, T. C., Das, K. M. and Kodali, V. P. (2014) 'Kinetic, equilibrium and thermodynamic studies of biosorption of Chromium (VI) from aqueous solutions using *Azolla filiculoidus*', *Journal of Pure and Applied Microbiology*, 8(4), 3107–3116.

Bahaa, S., Al-Baldawi, I. A., Yaseen, S. R. and Abdullah, S. R. S. (2019) ‘Biosorption of heavy metals from synthetic wastewater by using macro algae collected from Iraqi Marshlands’, *Journal of Ecological Engineering*, 20(11), 18–22.

Baig, J. A., Kazi, T. G., Shah, A. Q., Kandhro, G. A., Afridi, H. I., Khan, S. and Kolachi, N. F. (2010) ‘Biosorption studies on powder of stem of *Acacia nilotica*: Removal of arsenic from surface water’, *Journal of Hazardous Materials*, 178(1–3), 941–948.

Baig, S. A., Zhu, J., Muhammad, N., Sheng, T. and Xu, X. (2014) ‘Effect of synthesis methods on magnetic Kans grass biochar for enhanced As(III, V) adsorption from aqueous solutions’, *Biomass and Bioenergy*, 71, 299–310.

Bakare, A. A., Adeyemi, A. O., Adeyemi, A., Alabi, O. A. and Osibanjo, O. (2012) ‘Cytogenotoxic effects of electronic waste leachate in *Allium cepa*’, *International Journal of Cytology, Cytosystematics and Cytogenetics*, 65(2), 94–100.

Baral, S. S. (2011) Seaweed as an adsorbent to treat Cr (VI)-contaminated wastewater, Handbook of Marine Macroalgae: Biotechnology and Applied Phycology [online]. Available at: https://onlinelibrary.wiley.com/doi/book/10.1002/9781119977087#page=476 (Accessed: 21 January 2019).

Baral, S. S., Das, S. N. and Rath, P. (2006) ‘Hexavalent chromium removal from aqueous solution by adsorption on treated sawdust’, *Biochemical Engineering Journal*, 31, 216–222.

Barquilha, C. E. R., Cossich, E. S., Tavares, C. R. G. and Silva, E. A. da (2017) ‘Biosorption of Nickel (II) and Copper (II) ions in batch and fixed-bed columns by free and immobilized marine algae *Sargassum sp.*’, *Journal of Cleaner Production*, 150, 58–64.

Barquilha, C. E. R., Cossich, E. S., Tavares, C. R. G. and Silva, E. A. da (2019a) ‘Biosorption of Nickel (II) and Copper (II) ions from synthetic and real effluents by alginate-based biosorbent produced from seaweed *Sargassum sp.*’, *Environmental Science and Pollution Research*, 26(11), 11100–11112.

Barquilha, C. E. R., Cossich, E. S., Tavares, C. R. G. and Silva, E. A. da (2019b) ‘Biosorption of nickel and copper ions from synthetic solution and electroplating effluent using fixed bed column of immobilized brown algae’, *Journal of Water Process Engineering*, 32, 1–10.

Basha, S., Murthy, Z. V. P. and Jha, B. (2008a) ‘Biosorption of hexavalent chromium by chemically modified seaweed, *Cystoseira indica*’, *Chemical Engineering Journal*, 137, 480–488.

Basha, S., Murthy, Z. V. P. and Jha, B. (2008b) ‘Isotherm modeling for biosorption of Cu(II) and Ni(II) from wastewater onto brown seaweed, *Cystoseira indica*’, *Environmental and Energy Engineering*, 54(12), 3291–3302.

Basu, M., Guha, A. K. and Ray, L. (2017) ‘Adsorption of lead on cucumber peel’, *Journal of Cleaner Production*, 151, 603–615.

Benaisa, S., Arhoun, B., Villen-Guzman, M., Mail, R. E. and Rodriguez-Maroto, J. M. (2019) ‘Immobilization of brown seaweeds *Sargassum vulgare* for Fe^{3+} removal in batch and fixed-bed column’, *Water, Air, and Soil Pollution*, 230, 1–13.

Bertoni, F. A., Medeot, A. C., González, J. C., Sala, L. F. and Bellú, S. E. (2015) ‘Application of green seaweed biomass for Mo (VI) sorption from contaminated waters. Kinetic, thermodynamic and continuous sorption studies’, *Journal of Colloid and Interface Science*, 446, 122–132.

Biswas, S. and Mishra, U. (2015) ‘Continuous fixed-bed column study and adsorption modeling: Removal of lead ion from aqueous solution by charcoal originated from chemical carbonization of rubber wood sawdust’, *Journal of Chemistry*, 2015, 1–9.

Boddu, S., Dulla, J. B., Alugunulla, V. N. and Khan, A. A. (2020) ‘An assessment on removal performance of arsenic with treated *Turbinaria vulgaris* as an adsorbent: Characterization, optimization, isotherm, and kinetics study’, *Environmental Progress and Sustainable Energy*, 39(2), 1–13.

Borowska, S. and Brzóska, M. M. (2015) ‘Metals in cosmetics: Implications for human health’, *Journal of Applied Toxicology*, 35(6), 551–572.

Boulaiche, W., Belhamdi, B., Hamdi, B. and Trari, M. (2019) ‘Kinetic and equilibrium studies of biosorption of M (II) (M=Cu, Pb, Ni, Zn and Cd) onto seaweed *Posidonia oceanica* fibers’, *Applied Water Science*, 9(Article 173), 1–11.

Budi, S., Suliasih, B. A., Othman, M. S., Heng, L. Y. and Surif, S. (2015) ‘Toxicity identification evaluation of landfill leachate using fish, prawn and seed plant’, *Waste Management*, 55, 231–237.

Cardoso, S. L., Costa, C. S. D., Nishikawa, E., Silva, M. G. C. da and Vieira, M. G. A. (2017) ‘Biosorption of toxic metals using the alginate extraction residue from the brown algae *Sargassum filipendula* as a natural ion-exchanger', *Journal of Cleaner Production*, 165, 491–499.

Carolin, C. F., Kumar, P. S., Saravanan, A., Joshiba, G. J. and Naushad, M. (2017) 'Efficient techniques for the removal of toxic heavy metals from aquatic environment: A review', *Journal of Environmental Chemical Engineering*, 5, 2782–2799.

Carotenuto, M., Lofrano, G. and Sharma, S. K. (2015) 'Chapter 5: Arsenic contamination: An overview', in Sharma, S. K. (ed) *Heavy metals in water: Presence, removal and safety*. The Royal Society of Chemistry, pp. 86–121.

Cazón, J. P., Viera, M., Donati, E. and Guibal, E. (2013) 'Zinc and cadmium removal by biosorption on *Undaria pinnatifida* in batch and continuous processes', *Journal of Environmental Management*, 129, 423–434.

Ceylan, S. and Goldfarb, J. L. (2015) 'Green tide to green fuels: TG-FTIR analysis and kinetic study of *Ulva prolifera* pyrolysis', *Energy Conversion and Management*, 101, 263–270.

Chan, P. T. and Matanjun, P. (2017) 'Chemical composition and physicochemical properties of tropical red seaweed, *Gracilaria changii*', *Food Chemistry*, 221, 302–310.

Chan, P. T., Matanjun, P., Yasir, S. M. and Tan, T. S. (2014) 'Antioxidant and hypolipidaemic properties of red seaweed, *Gracilaria changii*', *Journal of Applied Phycology*, 26(2), 987–997.

Chan, P. T., Matanjun, P., Yasir, S. M. and Tan, T. S. (2016) 'Oxidative stress biomarkers in organs of hyperlipidaemic and normal rats fed tropical red seaweed, *Gracilaria changii*', *Journal of Applied Phycology*, 28(2), 1371–1378.

Chanzu, H. A., Onyari, J. M. and Shiundu, P. M. (2012) 'Biosorption of malachite green from aqueous solutions onto polylactide/spent brewery grains films: Kinetic and equilibrium studies', *Journal of Polymers and the Environment*, 20(3), 665–672.

Chao, H.-P., Chang, C.-C. and Nieva, A. (2014) 'Biosorption of heavy metals on *Citrus maxima* peel, passion fruit shell, and sugarcane bagasse in a fixed-bed column', *Journal of Industrial and Engineering Chemistry*, 20(5), 3408–3414.

Chatterjee, A. and Abraham, J. (2019) 'Desorption of heavy metals from metal loaded sorbents and e-wastes: A review', *Biotechnology Letters*, 41, 319–333.

Chaudhry, S. A., Khan, T. A. and Ali, I. (2017) 'Equilibrium, kinetic and thermodynamic studies of Cr(VI) adsorption from aqueous solution onto manganese oxide coated sand grain (MOCSG)', *Journal of Molecular Liquids*, 236, 320–330.

Chen, K., Rios, J. J., Perez-Galvez, A. and Roca, M. (2017) 'Comprehensive chlorophyll composition in the main edible seaweeds', *Food Chemistry*, 228, 625–633.

Chen, Z., Wang, Y., Li, K. and Zhou, H. (2014) 'Effects of increasing organic loading rate on performance and microbial community shift of an up-flow anaerobic sludge blanket reactor treating diluted pharmaceutical wastewater', *Journal of Bioscience and Bioengineering*, 118(3), 284–288.

Cheng-Guang, J., Ya-Ping, Z., He, W., Guang-Nan, O. U., Qi-Ming, L. and Jin-Mei, L. (2014) 'Rapid biosorption and reduction removal of Cr (VI) from aqueous solution by dried seaweeds', *Journal of Central South University*, 21(7), 2801–2809.

Cheng, S. Y., Show, P.-L., Juan, J. C., Chang, J.-S., Lau, B. F., Lai, S. H., Ng, E. P., Yian, H. C. and Ling, T. C. (2021) 'Landfill leachate wastewater treatment to facilitate resource recovery by a coagulation-flocculation process via hydrogen bond', *Chemosphere*, 262, 1–9.

Chowdhury, Z. Z., Zain, S. M., Rashid, A. K., Rafique, R. F. and Khalid, K. (2013) 'Breakthrough curve analysis for column dynamics sorption of Mn (II) ions from wastewater by using *Mangostana garcinia* peel-based granular-activated carbon', *Journal of Chemistry*, 2013, 1–8.

Christobel, J. and Lipton, A. P. (2015) 'Evaluation of macroalgal biomass for removal of heavy metal Arsenic (As) from aqueous solution', *International Journal of Application or Innovation in Engineering & Management*, 4(5), 94–104.

Chung, H.-K., Kim, W.-H., Park, J., Cho, J., Jeong, T.-Y. and Park, P.-K. (2015) 'Application of langmuir and freundlich isotherms to predict adsorbate removal efficiency or required amount of adsorbent', *Journal of Industrial and Engineering Chemistry*, 28, 241–246.

Cohen, S. M., Arnold, L. L., Beck, B. D., Lewis, A. S. and Eldan, M. (2013) 'Evaluation of the carcinogenicity of inorganic arsenic', *Critical Reviews in Toxicology*, 43(9), 711–752. doi: 10.3109/10408444.2013.827152.

Cortez, S., Teixeira, P., Oliveira, R. and Mota, M. (2008) ‘Rotating biological contactors: A review on main factors affecting performance’, *Reviews in Environmental Science and Biotechnology*, 7(2), 155–172.

Costa, C. S. D., Bertagnolli, C., Boos, A., Silva, M. G. C. da and Vieira, M. G. A. (2020) ‘Application of a dealginated seaweed derivative for the simultaneous metal ions removal from real and synthetic effluents’, *Journal of Water Process Engineering*, 37, 1–11.

Dan, A., Oka, M., Fujii, Y., Soda, S., Ishigaki, T., Machimura, T. and Ike, M. (2017) ‘Removal of heavy metals from synthetic landfill leachate in lab-scale vertical flow constructed wetlands’, *Science of the Total Environment*, 584–585, 742–750.

Das, C., Patel, P., De, S. and DasGupta, S. (2006) ‘Treatment of tanning effluent using nanofiltration followed by reverse osmosis’, *Separation and Purification Technology*, 50(3), 291–299.

Daud, Z., Abubakar, M. H., Kadir, A. A., Latiff, A. A. A., Awang, H., Halim, A. A. and Marto, A. (2017) ‘Adsorption studies of leachate on cockle shells’, *International Journal of GEOMATE*, 12(29), 46–52.

Davila-Guzman, N. E., Cerino-Córdova, F. J., Loredo-Cancino, M., Rangel-Mendez, J. R., Gómez-González, R. and Soto-Regalado, E. (2016) ‘Studies of adsorption of heavy metals onto spent coffee ground: Equilibrium, regeneration, and dynamic performance in a fixed-bed column’, *International Journal of Chemical Engineering*, 2016, 1–11.

Deacon, A. J. and Pratt, O. W. (2021) ‘Measurement of pulse oximetry, capnography and pH’, *Anaesthesia and Intensive Care Medicine*, 18(12), 639–643.

Debbarma, J., Rao, B. M., Murthy, L. N., Mathew, S., Venkateshwarlu, G. and Ravishankar, C. N. (2016) ‘Nutritional profiling of the edible seaweeds *Gracilaria edulis*, *Ulva lactuca* and *Sargassum sp*.’, *Indian Journal of Fisheries*, 63(3), 81–87.

Deepika, C. (2019) ‘FTIR, SEM, EDS and GCMS metabolite profiling of macroalgae–*Sargassum wightii*’, *International Research Journal of Engineering and Technology*, 6(3), 6791–6797.

Deng, L., Zhang, Y., Qin, J., Wang, X. and Zhu, X. (2009) ‘Biosorption of Cr (VI) from aqueous solutions by nonliving green algae *Cladophora albida*’, *Minerals Engineering*, 22(4), 372–377.

Deng, Y. and Zhao, R. (2015) ‘Advanced Oxidation Processes (AOPs) in wastewater treatment’, *Current Pollution Reports*, 1(3), 167–176.

Deniz, F. and Karabulut, A. (2017) ‘Biosorption of heavy metal ions by chemically modified biomass of coastal seaweed community: Studies on phycoremediation system modeling and design’, *Ecological Engineering*, 106(Part A), 101–108.

Devadoss, P. S. M., Agamuthu, P., Mehran, S. B., Santha, C. and Fauziah, S. H. (2021) ‘Implications of municipal solid waste management on greenhouse gas emissions in Malaysia and the way forward’, *Waste Management*, 119, 135–144.

Devi, S., Murugappan, A. and Kannan, R. R. (2014) ‘Sorption of reactive blue 19 onto freshwater algae and seaweed’, *Desalination and Water Treatment*, 54(9), 2611–2624.

Díaz-Vázquez, L. M., Rojas-Pérez, A., Fuentes-Caraballo, M., Robles, I. V., Jena, U. and Das, K. C. (2015) ‘Demineralization of *Sargassum spp*. macroalgae biomass: Selective hydrothermal liquefaction process for bio-oil production’, *Frontiers in Energy Research*, 3(Article 6), 1–11.

Diniz, V., Weber, M. E., Volesky, B. and Naja, G. (2008) ‘Column biosorption of lanthanum and europium by *Sargassum*’, *Water Research*, 42, 363–371.

Dittert, I. M., Brandao, H. de L., Pina, F., Silva, E. A. B. da, Souza, S. M. A. G. U. de, Souza, A. A. U. de, Botelho, C. M. S., Boaventura, R. A. R. and Vilar, B. J. P. (2014) ‘Integrated reduction/oxidation reactions and sorption processes for Cr (VI) removal from aqueous solutions using *Laminaria digitata* macro-algae’, *Chemical Engineering Journal*, 237, 443–454.

Dizge, N., Keskinler, B. and Barlas, H. (2009) ‘Sorption of Ni (II) ions from aqueous solution by Lewatit cation-exchange resin’, *Journal of Hazardous Materials*, 167(1–3), 915–926.

DOE (2010) Environmental requirements. *Eleventh Edition*. Putrajaya: Department of Environment.

Dohare, D. and Meshram, R. (2014) ‘Biological treatment of edible oil refinery wastewater activated sludge process and sequencing batch reactors-A review’, *International Journal of Engineering Sciences & Research Technology*, 3(12), 251–260.

Dolar, D., Košutic, K. and Strmecky, T. (2016) 'Hybrid processes for treatment of landfill leachate: Coagulation/UF/NF-RO and adsorption/UF/NF-RO', *Separation and Purification Technology*, 168, 39–46.

Dotto, G. L., Santos, J. M. N. dos, Rosa, R., Pinto, L. A. A., Pavan, F. A. and Lima, E. C. (2015) 'Fixed bed adsorption of methylene blue by ultrasonic surface modified chitin supported on sand', *Chemical Engineering Research and Design*, 100, 302–310.

Edris, G., Alhamed, Y. and Alzahrani, A. (2014) 'Biosorption of cadmium and lead from aqueous solutions by *Chlorella vulgaris* biomass: Equilibrium and kinetic study', *Arabian Journal for Science and Engineering*, 39, 87–93.

El-Fadel, M., Bou-Zeid, E. and Chahine, W. (2002) 'Long term simulations of leachate generation and transport from solid waste disposal at a former quarry site', *Journal of Solid Waste Technology and Management*, 28(2), 60–70.

El-Sheekh, M., El-Sabagh, S., Elsoud, G. A. and Elbeltagy, A. (2020) 'Efficacy of immobilized biomass of the seaweeds *Ulva lactuca* and *Ulva fasciata* for cadmium biosorption', *Iranian Journal of Science and Technology, Transactions A: Science*, 44, 37–49.

El-Sheekh, M., El-Sabagh, S., ElSouod, G. A. and Elbeltagy, A. (2019) 'Biosorption of cadmium from aqueous solution by free and immobilized dry biomass of *Chlorella vulgaris*', *International Journal of Environmental Research*, 13(3), 511–521.

El-Taweel, Y. A., Nassef, E. M., Elkheriany, I. and Sayed, D. (2015) 'Removal of Cr (VI) ions from waste water by electrocoagulation using iron electrode', *Egyptian Journal of Petroleum*, 183–192.

Elagroudy, S., Warith, M. A. and Zayat, M. El (2016). *Municipal solid waste management and green economy*. Germany: Global Young Academy.

Elmolla, E. S., Hamdy, W., Kassem, A. and Hady, A. A. (2016) 'Comparison of different rice straw based adsorbents for chromium removal from aqueous solutions', *Desalination and Water Treatment*, 57(15), 1–9.

EPA (2000). *832-F-00-015*. Wastewater Technology Fact Sheet: Trickling Filters, United States: Environmental Protection Agency, pp. 1–7.

EPA (2002). *832-F-02-008*. Wastewater Technology Fact Sheet: Aerated, Partial Mix Lagoons, United States: Environmental Protection Agency, pp. 1-5.

Erabee, I. K. (2017) Development of A Hybrid Technique by Integrating Electrolysis with Sago Palm Bark Activated Carbon to Treat Landfill Leachate. PhD Thesis, Universiti Putra Malaysia.

Erabee, I. K., Ahsan, A., Jose, B., Aziz, M. M. A., Ng, A. W. M., Idrus, S. and Daud, N. N. N. (2017) 'Adsorptive treatment of landfill leachate using activated carbon modified with three different methods', *KSCE Journal of Civil Engineering*, 1–13.

Erabee, I. K., Ahsan, A., Jose, B., Aziz, M. M. A., Ng, A. W. M., Idrus, S. and Daud, N. N. N. (2018) 'Adsorptive treatment of landfill leachate using activated carbon modified with three different methods', *KSCE Journal of Civil Engineering*, 22(4), 1083–1095.

Esmaeili, A., Beirami, P. and Ghasemi, S. (2011) 'Evaluation of the marine algae *Gracilaria* and its activated carbon for the adsorption of Ni (II) from wastewater', *E-Journal of Chemistry*, 8(4), 1512–1521. doi: 10.1155/2011/137484.

Esmaeili, A. and Beni, A. A. (2015) 'Biosorption of nickel and cobalt from plant effluent by *Sargassum glaucescens* nanoparticles at new membrane reactor', *International Journal of Environmental Science and Technology*, 12, 2055–2064.

Esmaeili, A. and Beni, A. A. (2018) 'Optimization and design of a continuous biosorption process using brown algae and chitosan/PVA nano-fiber membrane for removal of nickel by a new biosorbent', *International Journal of Environmental Science and Technology*, 15(4), 765–778.

Esposito, A., Pagnanelli, F., Lodi, A., Solisio, C. and Vegliò, F. (2001) 'Biosorption of heavy metals by *Sphaerotilus natans*: An equilibrium study at different pH and biomass concentrations', *Hydrometallurgy*, 60(2), 129–141.

Fauziah, S. H. and Agamuthu, P. (2012) 'Trends in sustainable landfilling in Malaysia, A developing country', *Waste Management and Research*, 30(7), 656–663.

Fazeli, A., Bakhtvar, F., Jahanshaloo, L., Sidik, N. A. C. and Bayat, A. E. (2016) 'Malaysia's stand on municipal solid waste conversion to energy: A review', *Renewable and Sustainable Energy Reviews*, 58, 1007–1016.

Fernandes, A., Pacheco, M. J., Ciríaco, L. and Lopes, A. (2015) 'Review on the electrochemical processes for the treatment of sanitary landfill leachates: Present and future', *Applied Catalysis B: Environmental*, 176–177, 183–200.

Filote, C., Ungureanu, G., Boaventura, R., Santos, S., Volf, I. and Botelho, C. (2017) ‘Green macroalgae from the Romanian coast of Black Sea: Physico-chemical characterization and future perspectives on their use as metal anions biosorbents’, *Process Safety and Environmental Protection*, 108, 34–43.

Filote, C., Volf, I., Santos, S. C. R. and Botelho, C. M. S. (2019) ‘Bioadsorptive removal of Pb(II) from aqueous solution by the biorefinery waste of *Fucus spiralis*’, *Science of the Total Environment*, 648, 1201–1209.

Francavilla, M., Franchi, M., Monteleone, M. and Caroppo, C. (2013) ‘The red seaweed *Gracilaria gracilis* as a multi products source’, *Marine Drugs*, 11(10), 3754–3776.

Fu, Y., Ding, X., Zhao, J. and Zheng, Z. (2020) ‘Study on the effect of oxidation-ultrasound treatment on the electrochemical properties of activated carbon materials’, *Ultrasonics - Sonochemistry*, 69, 1–8.

Gamal, A. A. E. (2010) ‘Biological importance of marine algae’, *Saudi Pharmaceutical Journal*, 18, 1–25.

Gao, J. L., Oloibiri, V., Chys, M., Audenaert, W., Decostere, B., He, Y., Langenhove, H. V., Demeestere, K. and Hulle, S. W. H. V. (2015) ‘The present status of landfill leachate treatment and its development trend from a technological point of view’, *Reviews in Environmental Science and Biotechnology*, 14(1), 93–122.

Gautam, R. K., Sharma, S. K., Mahiya, S. and Chattopadhyaya, M. C. (2014) ‘Chapter 1: Contamination of heavy metals in aquatic media: Transport, toxicity and technologies for remediation’, in Sharma, S. K. (ed) *Heavy metals in water: Presence, removal and safety*. The Royal Society of Chemistry, pp. 1–24.

Ghasemabadi, S. M., Baghdadi, M., Safari, E. and Ghazban, F. (2018) ‘Investigation of continuous adsorption of Pb (II), As (III), Cd (II), and Cr (VI) using a mixture of magnetic graphite oxide and sand as a medium in a fixed-bed column’, *Journal of Environmental Chemical Engineering*, 6(4), 4840–4849.

Ghasemi, F. F., Dobaradaran, S., Keshtkar, M., Mohammadi, M. J., Ghaedi, H. and Soleimani, F. (2016) ‘Biosorption of Mn (II) from aqueous solution by *Sargassum hystrix* algae obtained from the Persian Gulf: Biosorption isotherm and kinetic’, *International Journal of Pharmacy & Technology*, 8(3), 18227–18238.

Ghoneim, M. M., El-Desoky, H. S., El-Moselhy, K. M., Amer, A., El-Naga, E. H. A., Mohamedein, L. I. and Al-Prol, A. E. (2014) 'Removal of cadmium from aqueous solution using marine green algae, *Ulva lactuca*', *The Egyptian Journal of Aquatic Research*, 40(3), 235–242.

Godlewska, K., Marycz, K. and Michalak, I. (2018) 'Freshwater green macroalgae as a biosorbent of Cr (III) ions', *Open Chemistry*, 16, 689–701.

Gong, X., Huang, D., Liu, Y., Zeng, G., Wang, R., Wei, J., Huang, C., Xu, P., Wan, J. and Zhang, C. (2018) 'Pyrolysis and reutilization of plant residues after phytoremediation of heavy metals contaminated sediments: For heavy metals stabilization and dye adsorption', *Bioresource Technology*, 253, 64–71.

Goswami, L., Manikandan, N. A., Pakshirajan, K. and Pugazhenthi, G. (2017) 'Simultaneous heavy metal removal and anthracene biodegradation by the oleaginous bacteria *Rhodococcus opacus*', *3 Biotech*, 7(37), 1–9.

Guler, U. A. and Sarioglu, M. (2013) 'Single and binary biosorption of Cu(II), Ni(II) and methylene blue by raw and pretreated *Spirogyra sp.*: Equilibrium and kinetic modeling', *Journal of Environmental Chemical Engineering*, 1(3), 369–377.

Gupta, V. K. and Rastogi, A. (2008) 'Equilibrium and kinetic modelling of Cadmium (II) biosorption by nonliving algal biomass *Oedogonium sp*. from aqueous phase', *Journal of Hazardous Materials*, 153(1–2), 759–766.

Gupta, V. K. and Rastogi, A. (2009) 'Biosorption of hexavalent chromium by raw and acid-treated green alga *Oedogonium hatei* from aqueous solutions', *Journal of Hazardous Materials*, 163, 396–402.

Gutiérrez, C., Hansen, H. K., Hernández, P. and Pinilla, C. (2015) 'Biosorption of cadmium with brown macroalgae', *Chemosphere*, 138, 164–169.

Gutterres, M. and Mella, B. (2015) 'Chapter 16: Chromium in tannery wastewater', in Sharma, S. K. (ed) *Heavy metals in water: Presence, removal and safety*. The Royal Society of Chemistry, pp. 315–344.

Hackbarth, F. V., Girardi, F., Souza, S. M. A. G. U. de, Souza, A. A. U. de, Boaventura, R. A. R. and Vilar, V. J. P. (2014) 'Marine macroalgae *Pelvetia canaliculata* (Phaeophyceae) as a natural cation exchanger for cadmium and lead ions separation in aqueous solutions', *Chemical Engineering Journal*, 242, 294–305.

Hackbarth, F. V., Maass, D., Souza, A. A. U. de, Vilar, V. J. P. and Souza, S. M. A. G. U. de (2016) ‘Removal of hexavalent chromium from electroplating wastewaters using marine macroalga *Pelvetia canaliculata* as natural electron donor’, *Chemical Engineering Journal*, 290, 477–489.

Hajjizadeh, M., Ghammamy, S., Ganjidoust, H. and Farsad, F. (2020) ‘Amino acid modified bentonite clay as an eco-friendly adsorbent for landfill leachate treatment’, *Polish Journal of Environmental Studies*, 29(6), 4089–4099.

Hall, K. R., Eagleton, L. C., Acrivos, A. and Vermeulen, T. (1966) ‘Pore- and solid-diffusion kinetics in fixed-bed adsorption under constant-pattern conditions’, *Industrial & Engineering Chemistry Fundamentals*, 5(2), 212–223.

Hameed, B. H. (2009) ‘Evaluation of papaya seeds as a novel non-conventional low-cost adsorbent for removal of methylene blue’, *Journal of Hazardous Materials*, 162(2–3), 939–944.

Hannachi, Y., Rezgui, A., Dekhil, A. B. and Boubaker, T. (2015) ‘Removal of Cadmium (II) from aqueous solutions by biosorption onto the brown macroalga (*Dictyota dichotoma*)’, *Desalination and Water Treatment*, 54(6), 1663–1673.

Hansen, H. K., Ribeiro, A. and Mateus, E. (2006) ‘Biosorption of Arsenic (V) with *Lessonia nigrescens*’, *Minerals Engineering*, 19, 486–490.

Hara, T. (2020) '*Introduction: The sustainability of the world population*’, in An Essay on The Principle of Sustainable Population. Singapore: Springer, pp. 1–10.

Hassouni, H. E., Abdellaoui, D., Hani, S. E. and Bengueddour, R. (2014) ‘Biosorption of Cadmium (II) and Copper (II) from aqueous solution using red alga (*Osmundea pinnatifida*) biomass’, *J. Mater. Environ. Sci.*, 5(4), 967–974.

Hinks, J., Edwards, S., Sallis, P. J. and Caldwell, G. S. (2013) ‘The steady state anaerobic digestion of *Laminaria hyperborea*-Effect of hydraulic residence on biogas production and bacterial community composition’, *Bioresource Technology*, 143, 221–230.

Ho, Y.-S. (2006a) ‘Isotherms for the sorption of lead onto peat: Comparison of linear and non-linear methods’, *Polish Journal of Environmental Studies*, 15(1), 81–86.

Ho, Y.-S. (2006b) ‘Review of second-order models for adsorption systems’, *Journal of Hazardous Materials*, 681–689.

Ho, Y. S., Wase, D. A. J. and Forster, C. F. (1996) 'Kinetic studies of competitive heavy metal adsorption by *Sphagnum* moss peat', *Environmental Technology*, 17(1), 71–77.

Holdt, S. L. and Edwards, M. D. (2014) 'Cost-effective IMTA: A comparison of the production efficiencies of mussels and seaweed', *Journal of Applied Phycology*, 26(2), 933–945.

Hong, I. K., Jeon, H. and Lee, S. B. (2014) 'Comparison of red, brown and green seaweeds on enzymatic saccharification process', *Journal of Industrial and Engineering Chemistry*, 20(5), 2687–2691.

Hongbo, W. (2015). *The world population prospects: 2015 Revision*, United Nations: Department of Economic and Social Affairs, Population Division. Available at: https://www.un.org/en/development/desa/publications/world-population-prospects-2015-revision.html#:~:text=The%20current%20world%20population%20of,2015%20Revision%E2%80%9D%2C%20launched%20today. (Accessed: 7 July 2018).

Hoornweg, D. and Bhada-Tata, P. (2012) 'What a waste: A global review of solid waste management', *Urban Development Series; Knowledge Papers,* 15(March 2012), 1–116.

Huang, J.-C. and Shang, C. (2006) *Air stripping*, in Handbook of Environmental Engineering: Advanced Physicochemical Treatment Processes. Totowa: The Humana Press Inc., pp. 47–79.

Husien, S., Labena, A., El-Belely, E. F., Mahmoud, H. M. and Hamouda, A. S. (2019) 'Adsorption studies of hexavalent chromium [Cr (VI)] on micro-scale biomass of *Sargassum dentifolium*, seaweed', *Journal of Environmental Chemical Engineering*, 7(6), 1–12.

Hussein, M., Yoneda, K., Zaki, Z. M., Othman, N. and Amir, A. (2019) 'Leachate characterizations and pollution indices of active and closed unlined landfills in Malaysia', *Environmental Nanotechnology, Monitoring and Management*, 12, 1–9.

Ibrahim, Z. H. and Faruruwa, M. D. (2020) 'Biosorption studies of Cd^{2+} and Cr^{6+} from aqueous solution using cola-nut leaves as low-cost biosorbent', *Journal of Chemistry*, 2020, 1–10.

Idowu, I. A., Atherton, W., Hashim, K., Kot, P., Alkhaddar, R., Alo, B. I. and Shaw, A. (2019) ‘An analyses of the status of landfill classification systems in developing countries: Sub Saharan Africa landfill experiences’, *Waste Management*, 87, 761–771.

Idris, A., Inanc, B. and Hassan, M. N. (2004) ‘Overview of waste disposal and landfills/dumps in asian countries’, *Journal of Material Cycles and Waste Management*, 6(2), 104–110.

Indriatmoko, Heriyanto, Limantara, L. and Brotosudarmo, T. H. P. (2015) ‘Composition of photosynthetic pigments in a red alga *Kappaphycus alvarezi* cultivated in different depths’, *Procedia Chemistry*, 14, 193–201.

Inglezakis, V. J. (2007) ‘Solubility-normalized Dubinin-Astakhov adsorption isotherm for ion-exchange systems’, *Microporous and Mesoporous Materials*, 103(1–3), 72–81.

Iqbal, M. and Khera, R. A. (2015) ‘Adsorption of copper and lead in single and binary metal system onto *Fumaria indica* biomass’, *Chemistry International*, 1(4), 157b-163b.

Isa, A. M., Yusoff, M. S., Kamaruddin, M. A. and Aziz, H. A. (2017) Adsorption studies of COD and Fe^{2+} from stabilized landfill leachate on activated carbon and calcite containing alginate. *Proceedings of the International Conference of Global Network for Innovative Technology and AWAM International Conference in Civil Engineering*. 040015, 040015-1-040015–8. doi: 10.1063/1.5005695.

Ishak, A. R., Mohamad, S., Soo, T. K. and Hamid, F. S. (2016) ‘Leachate and surface water characterization and heavy metal health risk on cockles in Kuala Selangor’, *Procedia - Social and Behavioral Sciences*, 222, 263–271.

Ishak, W. M. F. B. W. and Hamzah, S. S. B. (2010) Application of seaweed as an alternative for leachate treatment of heavy metal. *International Conference on Chemistry and Chemical Engineering (ICCCE 2010)*. 1-3 August. Kyoto, Japan: IEEE, 232–235. doi: 10.1109/ICCCENG.2010.5560448.

Ishwarya, R., Vaseeharan, B., Kalyani, S., Banumathi, B., Govindarajan, M., Alharbi, N. S., Kadaikunnan, S., Al-anbr, M. N., Khaled, J. M. and Benelli, G. (2018) ‘Facile green synthesis of zinc oxide nanoparticles using *Ulva lactuca* seaweed extract and evaluation of their photocatalytic, antibiofilm and insecticidal activity', *Journal of Photochemistry and Photobiology, B: Biology*, 178, 249–258.

Islam, M. S., Ahmed, M. K., Raknuzzaman, M., Mamun, M. H.-A.- and Islam, M. K. (2015) 'Heavy metal pollution in surface water and sediment: A preliminary assessment of an urban river in a developing country', *Ecological Indicator*, 48, 282–291.

Ismail, M. G. B. H., Weng, C. N., Rahman, H. A. and Zakaria, N. A. (2013) 'Freundlich isotherm equilibrium equations in determining effectiveness a low cost absorbent to heavy metal removal in wastewater (leachate) at Teluk Kitang Landfill, Pengkalan Chepa, Kelantan, Malaysia', *Journal of Geography and Earth Science*, 1(1), 1–8.

Jaafari, J. and Yaghmaeian, K. (2019) 'Optimization of heavy metal biosorption onto freshwater algae (*Chlorella coloniales*) using Response Surface Methodology (RSM)', *Chemosphere*, 447–455.

Jafari, S. A., Jamali, A. and Hosseini, A. (2015) 'Cadmium removal from aqueous solution by brown seaweed, *Sargassum angustifolium*', *Korean Journal of Chemical Engineering*, 32(10), 2053–2066.

Jafarinejad, S. (2017) 'Recent developments in the application of Sequencing Batch Reactor (SBR) technology for the petroleum industry wastewater treatment', *Chemistry International*, 3(3), 241–250.

Jain, C. K. and Ali, I. (2000) 'Arsenic: Occurrence, toxicity and speciation techniques', *Water Research*, 34(17), 4304–4312.

Jalil, H. (2016, February 4) Landfills is the way forward for Malaysia, Says Abdul Rahman Dahlan. *the Sun daily*. Retrieved May 13, 2018, from https://www.thesundaily.my/archive/1686458-MSARCH349131.

Jayakumar, R., Rajasimman, M. and Karthikeyan, C. (2014) 'Sorption of hexavalent chromium from aqueous solution using marine green algae *Halimeda gracilis*: Optimization, equilibrium, kinetic, thermodynamic and desorption studies', *Journal of Environmental Chemical Engineering*, 1261–1274.

Jayanthi, B., Emenike, C. U., Agamuthu, P., Simarani, K., Mohamad, S. and Fauziah, S. H. (2016) 'Selected microbial diversity of contaminated landfill soil of Peninsular Malaysia and the behavior towards heavy metal exposure', *Catena*, 147, 25–31.

Jayanthi, B., Emenike, C. U., Auta, S. H., Agamuthu, P. and Fauziah, S. H. (2017) 'Characterization of induced metal responses of bacteria isolates from active non-sanitary landfill in Malaysia', *International Biodeterioration and Biodegradation*, 119, 467–475.

Jeon, C. (2015) 'Adsorption behavior of silver ions from industrial wastewater onto immobilized crab shell beads', *Journal of Industrial and Engineering Chemistry*, 32, 195–200.

Jong, L. W., Thien, V. Y., Yong, Y. S., Rodrigues, K. F. and Yong, W. T. L. (2015) 'Micropropagation and protein profile analysis by SDS-PAGE of *Gracilaria changii* (Rhodophyta, Solieriaceae)', *Aquaculture Reports*, 1, 10–14.

Jumaah, M. A., Othman, M. R. and Yusop, M. R. (2016a) 'Characterization of leachate from Jeram Sanitary Landfill-Malaysia', *International Journal of ChemTech Research*, 9(8), 571–574.

Jumaah, M. A., Othman, M. R. and Yusop, M. R. (2016b) 'Electrochemical treatment of landfill leachate: Optimization of COD removal using charcoal-graphite-cobalt-polyvinyl chloride electrode', *Research Journal of Pharmaceutical , Biological and Chemical Sciences*, 7(5), 2812–2816.

Juneja, S., Sudhakar, S., Khonina, S. N., Skidanov, R. V., Porfirev, A. P., Moissev, O. Y., Kazanskiy, N. L. and Kumar, S. (2016) Nanocrystalline silicon thin films and grating structures for solar cells. *XIII International Scientific and Technical Conference on Optical Technologies for Telecommunications*. 2015. 1-8. doi: 10.1117/12.2232326.

Júnior, W. J. N., Silva, M. G. C. and Vieira, M. G. A. (2020) 'Competitive fixed-bed biosorption of Ag (I) and Cu (II) ions on *Sargassum filipendula* seaweed waste', *Journal of Water Process Engineering*, 36, 1–12.

Kadir, A., Mustafa, M., Bakri, A., Sandu, A. V., Noor, N. M., Lisanah, A., Latif, A. and Hussin, K. (2014) 'Usage of palm shell activated carbon to treat landfill leachate', *International Journal of Conservation Science*, 5(1), 117–126.

Kamali, M. and Khodaparast, Z. (2015) 'Review on recent developments on pulp and paper mill wastewater treatment', *Ecotoxicology and Environmental Safety*, 114, 326–342.

Kamaruddin, M. A., Abdullah, M. M. A., Yusoff, M. S., Alrozi, R. and Neculai, O. (2017) Coagulation-flocculation process in landfill leachate treatment: Focus on coagulants and coagulants aid. *International Conference on Innovative Research*. 209, 1-7.

Kamaruddin, M. A., Yusoff, M. S., Aziz, H. A. and Hung, Y.-T. (2015) 'Sustainable treatment of landfill leachate', *Applied Water Science*, 5(2), 113–126.

Kannan, S. (2014) 'FT-IR and EDS analysis of the seaweeds *Sargassum wightii* (brown algae) and *Gracilaria corticata* (Red Algae)', *International Journal of Current Microbiology and Applied Sciences*, 3(4), 341–351.

Karthikeyan, S., Balasubramanian, R. and Iyer, C. S. P. (2007) 'Evaluation of the marine algae *Ulva fasciata* and *Sargassum sp.* for the biosorption of Cu (II) from aqueous solutions', *Bioresource Technology*, 98, 452–455.

Kasman, M. and Ibrahim, S. (2016) 'The removal of iron from landfill leachate by rice husk packed bed column', *Journal of Chemical and Pharmaceutical Research*, 8(8), 1255–1262.

Kasmuri, N. and Tarmizi, N. A. A. (2018) 'The treatment of landfill leachate by electrocoagulation to reduce heavy metals and ammonia-nitrogen', *International Journal of Engineering and Technology*, 7(3.11), 109–112.

Kawai, K. and Tasaki, T. (2016) 'Revisiting estimates of municipal solid waste generation per capita and their reliability', *Journal of Material Cycles and Waste Management*, 18, 1–13.

Kawai, M., Nagao, N., Kawasaki, N., Imai, A. and Toda, T. (2016) 'Improvement of COD removal by controlling the substrate degradability during the anaerobic digestion of recalcitrant wastewater', *Journal of Environmental Management*, 181, 838–846.

Keng, P.-S., Lee, S.-L., Ha, S.-T., Hung, Y.-T. and Ong, S.-T. (2014) 'Removal of hazardous heavy metals from aqueous environment by low-cost adsorption materials', *Environmental Chemistry Letters*, 12(1), 15–25.

Ketsela, G., Animen, Z. and Talema, A. (2020) 'Adsorption of Lead (II), Cobalt (II) and Iron (II) from aqueous solution by activated carbon prepared from white lupine (GIBITO) husk', *Journal of Thermodynamics and Catalysis*, 11(2), 1–8.

Khan, A. A., Gaur, R. Z., Tyagi, V. K., Khursheed, A., Lew, B., Mehrotra, I. and Kazmi, A. A. (2011) 'Sustainable options of post treatment of UASB effluent treating sewage: A review', *Resources, Conservation and Recycling*, 55(12), 1232–1251.

Khan, D., Kumar, A. and Samadder, S. R. (2016) 'Impact of socioeconomic status on municipal solid waste generation rate', *Waste Management*, 49, 15–25.

Kim, B.-S., Lee, H. W., Park, S. H., Baek, K., Jeon, J.-K., Cho, H. J., Jung, S.-C., Kim, S. C. and Park, Y.-K. (2016) 'Removal of Cu^{2+} by biochars derived from green macroalgae', *Environmental Science and Pollution Research*, 23, 985–994.

Kim, J. K., Yarish, C., Hwang, E. K., Park, M. and Kim, Y. (2017) 'Seaweed aquaculture: Cultivation technologies, challenges and its ecosystem services', *Algae*, 32(1), 1–13.

Kosek-hoehne, K., Panocha, B. and Śliwa, A. (2017) 'Heavy metals – A silent threat to health', *Journal of Education, Health and Sport*, 7(1), 121–132.

Koutahzadeh, N., Daneshvar, E., Kousha, M., Sohrabi, M. S. and Bhatnagar, A. (2013) 'Biosorption of hexavalent chromium from aqueous solution by six brown macroalgae', *Desalination and Water Treatment*, 51(31–33), 6021–6030.

Kowanga, K. D., Gatebe, E., Mauti, G. O. and Mauti, E. M. (2016) 'Kinetic, sorption isotherms, pseudo-first-order model and pseudo-second-order model studies of Cu(II) and Pb(II) using defatted *Moringa oleifera* seed powder', *The Journal of Phytopharmacology*, 5(2), 71–78.

Kucuker, M. A., Wieczorek, N., Kuchta, K. and Copty, N. K. (2017) 'Biosorption of neodymium on *Chlorella vulgaris* in aqueous solution obtained from hard disk drive magnets', *PLoS ONE*, 12(4), 1–13.

Kumar, J. I. N., Oommen, C. and Kumar, R. N. (2009) 'Biosorption of heavy metals from aqueous solution by green marine macroalgae from Okha Port, Gulf of Kutch, India', *American-Eurasian J. Agric. & Enviorn. Sci.*, 6(3), 317–323.

Kumar, M., Gupta, V., Kumari, P., Reddy, C. R. K. and Jha, B. (2011) 'Assessment of nutrient composition and antioxidant potential of *Caulerpaceae seaweeds*', *Journal of Food Composition and Analysis*, 24(2), 270–278.

Kumar, M., Singh, A. K. and Sikandar, M. (2018) 'Study of sorption and desorption of Cd (II) from aqueous solution using isolated green algae *Chlorella vulgaris*', *Applied Water Science*, 8(225), 1–11.

Kumar, S., Katoria, D. and Singh, G. (2013) 'Leachate treatment technologies', *International Journal of Environmental Engineering and Management*, 4(5), 439–444.

Kyzas, G. Z., Lazaridis, N. K. and Kostoglou, M. (2014) 'Adsorption/desorption of a dye by a chitosan derivative: Experiments and phenomenological modeling', *Chemical Engineering Journal*, 248, 327–336.

Lakshmi, D. S., Trivedi, N. and Reddy, C. R. K. (2017) 'Synthesis and characterization of seaweed cellulose derived carboxymethyl cellulose', *Carbohydrate Polymers*, 157, 1604–1610.

Lakshmipathy, R. and Sarada, N. C. (2015) 'A fixed bed column study for the removal of Pb^{2+} ions by watermelon rind', *Environmental Science: Water Research and Technology*, 1, 244–250.

Lasheen, M. R., Ammar, N. S. and Ibrahim, H. S. (2012) 'Adsorption/desorption of Cd(II), Cu(II) and Pb(II) using chemically modified orange peel: Equilibrium and kinetic studies', *Solid State Sciences*, 14(2), 202–210.

Lebron, Y. A. R., Moreira, V. R., Brasil, Y. L., Silva, A. F. R., Santos, L. V. de S., Lange, L. C. and Amaral, M. C. S. (2021) 'A survey on experiences in leachate treatment: Common practices, differences worldwide and future perspectives', *Journal of Environmental Management*, 288, 1–20.

Lee, K. O., Ramli, N., Said, M., Ahmad, M., Yasir, S. M. and Ariff, A. (2011) 'Copper (II) and Nickel (II) sorption onto seaweed (*Kappaphycus alvarezii*) waste biomass: Equilibrium and mechanism studies', *Middle-East Journal of Scientific Research*, 9(1), 84–89.

Lee, W.-K., Lim, Y.-Y., Leow, A. T.-C., Namasivayam, P., Abdullah, J. O. and Ho, C.-L. (2017) 'Factors affecting yield and gelling properties of agar', *Journal of Applied Phycology*, 29(3), 1527–1540.

Li, W., Zhou, Q. and Hua, T. (2010) 'Removal of organic matter from landfill leachate by advanced oxidation processes: A review', *International Journal of Chemical Engineering*, 1–10.

Li, Y.-L., Wang, J., Yue, Z.-B., Tao, W., Yang, H.-B., Zhou, Y.-F. and Chen, T.-H. (2017) 'Simultaneous chemical oxygen demand removal, methane production and heavy metal precipitation in the biological treatment of landfill leachate using acid mine drainage as sulfate resource', *Journal of Bioscience and Bioengineering*, 124(1), 71–75.

Li, Y. X., Wang, Y. and Zhao, F. J. (2015) 'Kinetic and equilibrium studies of Chromium (VI) biosorption by spent macroalgae *Polysiphonia urceolata* and

Chondrus ocellatus', *Biotechnology and Biotechnological Equipment*, 29(3), 498–505.

Libatique, M. J. H., Lee, M. and Yeh, H. (2020) 'Effect of light intensity on the mechanism of inorganic arsenic accumulation and patterns in the red macroalga, *Sarcodia suiae*', *Biological Trace Element Research*, 195, 291–300.

Lim, A. P. and Aris, A. Z. (2014) 'Continuous fixed-bed column study and adsorption modeling: Removal of cadmium (II) and lead (II) ions in aqueous solution by dead calcareous skeletons', *Biochemical Engineering Journal*, 87, 50–61.

Lim, C. K., Seow, T. W., Neoh, C. H., Nor, M. H. M., Ibrahim, Z., Ware, I. and Sarip, S. H. M. (2016) 'Treatment of landfill leachate using ASBR combined with zeolite adsorption technology', *3 Biotech*, 6(2), 195–200.

Lim, S. J. and Kim, T.-H. (2014) 'Applicability and trends of anaerobic granular sludge treatment processes', *Biomass and Bioenergy*, 60, 189–202.

Ling, A. L. M., Yasir, S., Matanjun, P. and Bakar, M. F. A. (2015) 'Effect of different drying techniques on the phytochemical content and antioxidant activity of *Kappaphycus alvarezii*', *Journal of Applied Phycology*, 27, 1717–1723.

Liu, S. (2013) Landfill Leachate Treatment Methods and Evaluation of Hedeskoga and Måsalycke Landfills. Master Thesis, Lund University, Sweden.

Lonappan, L., Rouissi, T., Liu, Y., Brar, S. K. and Surampalli, R. Y. (2019) 'Removal of diclofenac using microbiochar fixed-bed column bioreactor', *Journal of Environmental Chemical Engineering*, 7(1), 1–8.

Long, C., Chen, X., Jiang, L., Zhi, L. and Fan, Z. (2015) 'Porous layer-stacking carbon derived from in-built template in biomass for high volumetric performance supercapacitors', *Nano Energy*, 12, 141–151.

Long, J., Huang, X., Fan, X., Peng, Y. and Xia, J. (2018) 'Effective adsorption of Nickel (II) with *Ulva lactuca* dried biomass: Isotherms, kinetics and mechanisms', *Water Science and Technology*, 78(1), 156–164.

Luo, H., Wang, Q., Liu, Z., Wang, S., Long, A. and Yang, Y. (2020) 'Potential bioremediation effects of seaweed *Gracilaria lemaneiformis* on heavy metals in coastal sediment from a typical mariculture zone', *Chemosphere*, 245, 1–31.

Ma, Z., Chen, D., Gu, J., Bao, B. and Zhang, Q. (2015) 'Determination of pyrolysis characteristics and kinetics of palm kernel shell using TGA-FTIR and model-free integral methods', *Energy Conversion and Management*, 89, 251–259.

Mahmood, Z., Zahra, S., Iqbal, M., Raza, M. A. and Nasir, S. (2017) 'Comparative study of natural and modified biomass of *Sargassum sp.* for removal of Cd^{2+} and Zn^{2+} from wastewater', *Applied Water Science*, 7, 3469–3481.

Mahmoodi, N. M. and Mokhtari-Shourijeh, Z. (2016) 'Modified Poly(Vinyl Alcohol)-Triethylenetetramine nanofiber by glutaraldehyde: Preparation and dye removal ability from wastewater', *Desalination and Water Treatment*, 57(42), 20076–20083.

Mahurpawar, M. (2015) 'Effects of heavy metals on human health', *International Journal of Research*, 1–7.

Maji, S. K., Pal, A., Pal, T. and Adak, A. (2007) 'Modeling and fixed bed column adsorption of As (V) on laterite soil', *Journal of Environmental Science and Health - Part A Toxic/Hazardous Substances and Environmental Engineering*, 42(11), 1585–1593.

Makkar, H. P. S., Tran, G., Heuzé, V., Giger-Reverdin, S., Lessire, M., Lebas, F. and Ankers, P. (2016) 'Seaweeds for livestock diets: A review', *Animal Feed Science and Technology*, 212, 1–17.

Mamais, D., Noutsopoulos, C., Kavallari, I., Nyktari, E., Kaldis, A., Panousi, E., Nikitopoulos, G., Antoniou, K. and Nasioka, M. (2016) 'Biological groundwater treatment for chromium removal at low hexavalent chromium concentrations', *Chemosphere*, 152, 238–244.

Mamun, A. A., Alam, M. Z., Mohd, N. A. N. and Rashid, S. S. (2011) 'Adsorption of heavy metal from landfill leachate by wasted biosolids', *African Journal of Biotechnology*, 10(81), 18869–18881.

Mandal, P., Dubey, B. K. and Gupta, A. K. (2017) 'Review on landfill leachate treatment by electrochemical oxidation: Drawbacks, challenges and future scope', *Waste Management*, 69, 250–273.

Mansouri, B., Salehi, J. and Rezaei, M. (2014) 'Leachate and pollution levels of heavy metals in the groundwater near municipal solid waste landfill site of Mashhad, Iran', *Iranian Journal of Toxicology*, 8(25), 1068–1072.

Martins, T. H., Souza, T. S. O. and Foresti, E. (2017) 'Ammonium removal from landfill leachate by clinoptilolite adsorption followed by bioregeneration', *Journal of Environmental Chemical Engineering*, 5(1), 63–68.

Mata, Y. N., Blázquez, M. L., Ballester, A., González, F. and Muñoz, J. A. (2008) 'Characterization of the biosorption of cadmium, lead and copper with the brown alga *Fucus vesiculosus*', *Journal of Hazardous Materials*, 158, 316–323.

Matanjun, P., Mohamed, S., Mustapha, N. M. and Muhammad, K. (2009) 'Nutrient content of tropical edible seaweeds, *Eucheuma cottonii*, *Caulerpa lentillifera* and *Sargassum polycystum*', *Journal of Applied Phycology*, 21(1), 75–80.

Matouq, M., Jildeh, N., Qtaishat, M., Hindiyeh, M. and Syouf, M. Q. A. (2015) 'The adsorption kinetics and modeling for heavy metals removal from wastewater by Moringa pods', *Journal of Environmental Chemical Engineering*, 3(2), 775–784.

McKay, G., Blair, H. S. and Gardner, J. R. (1982) 'Adsorption of dyes on chitin. I. Equilibrium studies', *Journal of Applied Polymer Science*, 27, 3043–3057.

Meeroff, D. E., Bloetscher, F., Reddy, D. V., Gasnier, F., Jain, S., McBarnette, A. and Hamaguchi, H. (2012) 'Application of photochemical technologies for treatment of landfill leachate', *Journal of Hazardous Materials*, 209–210, 299–307.

Michalak, I., Baśladyńska, S., Mokrzycki, J. and Rutkowski, P. (2019) 'Biochar from a freshwater macroalga as a potential biosorbent for wastewater treatment', *Water*, 11(7), 1–16.

Michalak, I. and Chojnacka, K. (2010) 'Interactions of metal cations with anionic groups on the cell wall of the macroalga *Vaucheria sp.*', *Engineering in Life Sciences*, 10(3), 209–217.

Michalak, I., Chojnacka, K. and Marycz, K. (2011) 'Using ICP-OES and SEM-EDX in biosorption studies', *Microchimica Acta*, 172, 65–74.

Michalak, I., Mironiuk, M. and Marycz, K. (2018) 'A comprehensive analysis of biosorption of metal ions by macroalgae using ICP-OES, SEM-EDX and FTIR techniques', *PLoS ONE*, 13(10), 1–20.

Milani, P. A., Debs, K. B., Labuto, G. and Carrilho, E. N. V. M. (2018) 'Agricultural solid waste for sorption of metal ions: Part I—Characterization and use of lettuce roots and sugarcane bagasse for Cu(II), Fe(II), Zn(II), and Mn(II) sorption from aqueous medium', *Environmental Science and Pollution Research*, 25(36), 35895–35905.

Mishra, A., Tripathi, B. D. and Rai, A. K. (2014) 'Biosorption of Cr (VI) and Ni (II) onto *Hydrilla verticillata* dried biomass', *Ecological Engineering*, 73, 713–723.

Mittal, A. (2011) Biological wastewater treatment. *Water Today,* August, 32–44.

Moghadam, M. R., Jahromi, S. M. P. and Darehkordi, A. (2016) 'Simultaneous spectrophotometric determination of copper, cobalt, nickel and iron in foodstuffs and vegetables with a new bis thiosemicarbazone ligand using chemometric approaches', *Food Chemistry,* 192, 424–431.

Moh, Y. C. and Manaf, L. A. (2017) 'Solid waste management transformation and future challenges of source separation and recycling practice in Malaysia', *Resources, Conservation and Recycling*, 116, 1–14.

Mohamad, I. I., Yunus, M. Z. M. and Ahmad, F. S. (2016) 'Landfill site selection by integrating analytical hierarchy process and geographic information system', *Malaysian Journal of Civil Engineering*, 28(3), 180–191.

Mohamad, M., Abustan, I., Samuding, K., Mohamad, A. and Mohamad, N. (2017) 'Enhancement of landfill daily cover in minimizing the migration of heavy metals in landfill leachate by using natural soil, pressmud & empty fruit bunch (EFB) in Pulau Burung Landfill', *International Journal of Advanced Engineering, Management and Science*, 3(1), 37–47.

Mohammad-pajooh, E., Weichgrebe, D. and Cuff, G. (2017) 'Municipal landfill leachate characteristics and feasibility of retrofitting existing treatment systems with deammonification-A full scale survey', *Journal of Environmental Management*, 187, 354–364.

Mohammed, K. and Sahu, O. (2015) 'Bioadsorption and membrane technology for reduction and recovery of chromium from tannery industry wastewater', *Environmental Technology and Innovation*, 4, 150–158.

Mohd-Salleh, S. N. A., Shaylinda, M. Z. N., Othman, N., Azizan, M. O., Yashni, G. and Afnizan, W. M. W. (2020) Sustainability analysis on landfilling and evaluation of characteristics in landfill leachate: A case study. *Energy Security and Chemical Engineering Congress*. 736, 1–13. doi: 10.1088/1757-899X/736/7/072002.

Moino, B. P., Costa, C. S. D., Silva, M. G. C. da and Vieira, M. G. A. (2017) 'Removal of nickel ions on residue of alginate extraction from *Sargassum filipendula* seaweed in packed bed', *The Canadian Journal of Chemical Engineering*, 95(11), 2120–2128.

Mojiri, A., Aziz, H. A. and Aziz, S. Q. (2013) 'Trends in physical-chemical methods for landfill leachate treatment', *International Journal of Scientific Research in Environmental Sciences*, 1(2), 16–25.

Mojiri, A., Aziz, H. A., Zaman, N. Q., Aziz, S. Q. and Zahed, M. A. (2014) 'Powdered ZELIAC augmented Sequencing Batch Reactors (SBR) process for co-treatment of landfill leachate and domestic wastewater', *Journal of Environmental Management*, 139, 1–14.

Mojiri, A., Aziz, H. A., Zaman, N. Q., Aziz, S. Q. and Zahed, M. A. (2016) 'Metals removal from municipal landfill leachate and wastewater using adsorbents combined with biological method', *Desalination and Water Treatment*, 57(6), 2819–2833.

Mokrzycki, J., Michalak, I. and Rutkowski, P. (2020) 'Biochars obtained from freshwater biomass—green macroalga and hornwort as Cr (III) ions sorbents', *Biomass Conversion and Biorefinery*. doi: 10.1007/s13399-020-00649-6.

Mondal, K., Kumari, P. and Manam, J. (2016) 'Influence of doping and annealing temperature on the structural and optical properties of $Mg_2SiO_4:Eu^{3+}$ synthesized by combustion method', *Current Applied Physics*, 16(7), 707–719.

Morosanu, I., Teodosiu, C., Paduraru, C., Ibanescu, D. and Tofan, L. (2017) 'Biosorption of lead ions from aqueous effluents by rapeseed biomass', *New Biotechnology*, 39(Part A), 110–124.

Moussa, D. T., El-Naas, M. H., Nasser, M. and Al-Marri, M. J. (2017) 'A comprehensive review of electrocoagulation for water treatment: Potentials and challenges', *Journal of Environmental Management*, 186, 24–41.

Mowla, D., Karimi, G. and Salehi, K. (2013) 'Modeling of the adsorption breakthrough behaviors of oil from salty waters in a fixed bed of commercial organoclay/sand mixture', *Chemical Engineering Journal*, 218, 116–125.

Mukherjee, S., Mukhopadhyay, S., Zafri, M. Z. B., Zhan, X., Hashim, M. A. and Gupta, B. S. (2018) 'Application of guar gum for the removal of dissolved lead from wastewater', *Industrial Crops & Products*, 111, 261–269.

Murphy, V., Hughes, H. and McLoughlin, P. (2008) 'Comparative study of chromium biosorption by red, green and brown seaweed biomass', *Chemosphere*, 70(6), 1128–1134.

Mustafa, E.-M., Phang, S.-M. and Chu, W.-L. (2012) ‘Use of an algal consortium of five algae in the treatment of landfill leachate using the high-rate algal pond system’, *Journal of Applied Phycology*, 24, 953–963.

Mutalib, M. A., Rahman, M. A., Othman, M. H. D., Ismail, A. F. and Jaafar, J. (2017) ‘Chapter 9 - Scanning Electron Microscopy (SEM) and Energy-Dispersive X-Ray (EDX) spectroscopy’, in Hilal, N., Ismail, A. F., Matsuura, T. and Oatley-Radcliffe, D. (eds) *Membrane characterization*. Elsevier B. V., pp. 161–179.

Mwalugha, H. M., Wakibia, J. G., Kenji, G. M. and Mwasaru, M. A. (2015) ‘Chemical composition of common seaweeds from the Kenya coast’, *Journal of Food Research*, 4(6), 28–38.

Nandiyanto, A. B. D. and Haristiani, N. (2017) Design of simple water treatment system for cleaning dirty water in the rural area. *1st Annual Applied Science and Engineering Conference*. 180(1), 1–8.

Naushad, M., Othman, Z. A. A., Sharma, G. and Inamuddin (2015) ‘Kinetics, isotherm and thermodynamic investigations for the adsorption of Co (II) Ion onto crystal violet modified amberlite IR-120 resin’, *Ionics*, 21(5), 1453–1459.

Naveen, B. P., Mahapatra, D. M., Sitharam, T. G., Sivapullaiah, P. V. and Ramachandra, T. V. (2017) ‘Physico-chemical and biological characterization of urban municipal landfill leachate’, *Environmental Pollution*, 220(Part A), 1–12.

Nawaz, M. S. and Ahsan, M. (2014) ‘Comparison of physico-chemical, advanced oxidation and biological techniques for the textile wastewater treatment’, *Alexandria Engineering Journal*, 53(3), 717–722.

Nayak, A., Bhushan, B., Gupta, V. and Sharma, P. (2017) ‘Chemically activated carbon from lignocellulosic wastes for heavy metal wastewater remediation: Effect of activation conditions’, *Journal of Colloid and Interface Science*, 493, 228–240.

Ng, K. S. and Iacovidou, E. (2020). Malaysia versus waste. *Institution of Chemical Engineers*, 1.

Nguyen, T. C., Loganathan, P., Nguyen, T. V., Vigneswaran, S., Kandasamy, J. and Naidu, R. (2015) ‘Simultaneous adsorption of Cd, Cr, Cu, Pb, and Zn by an iron-coated Australian zeolite in batch and fixed-bed column studies’, *Chemical Engineering Journal*, 270, 393–404.

Niu, C. H., Volesky, B. and Cleiman, D. (2007) ‘Biosorption of Arsenic (V) with acid-washed crab shells’, *Water Research*, 41, 2473–2478.

Nkemka, V. N. and Murto, M. (2010) ‘Evaluation of biogas production from seaweed in batch tests and in UASB reactors combined with the removal of heavy metals’, *Journal of Environmental Management*, 91(7), 1573–1579.

Nkemka, V. N. and Murto, M. (2012) ‘Exploring strategies for seaweed hydrolysis: Effect on methane potential and heavy metal mobilisation’, *Process Biochemistry*, 47(12), 2523–2526.

Nor, N. M. S., Siti, R. M. Y., Subramaniam, K., Hazilia, H. and Amir, H. A. (2015) ‘Characterization of leachate from Panchang Bedena Landfill, Batang Padang Landfill and Matang Landfill: A comparative study’, *Malaysian Journal of Science*, 34(1), 69–77.

Norziah, M. H. and Ching, C. Y. (2000) ‘Nutritional composition of edible seaweed *Gracilaria changgi*’, *Food Chemistry*, 68(1), 69–76.

Nouha, K., Kumar, R. S. and Tyagi, R. D. (2016) ‘Heavy metals removal from wastewater using extracellular polymeric substances produced by *Cloacibacterium normanense* in wastewater sludge supplemented with crude glycerol and study of extracellular polymeric substances extraction by different methods’, *Bioresource Technology*, 212, 120–129.

NSWMD (2015). *Ringkasan Tapak Pelupusan Sisa Pepejal di Malaysia*, Malaysia: Ministry of Urban Wellbeing, Housing and Local Government. Available at: https://jpspn.kpkt.gov.my/resources/index/user_1/Sumber_Rujukan/statistik/ringkasan_tapak_seluruh_Malaysia.pdf (Accessed: 10 March 2017).

Oliveira, M. N. de, Freitas, A. L. P., Carvalho, A. F. U., Sampaio, T. M. T., Farias, D. F., Teixeira, D. I. A., Gouveia, S. T., Pereira, J. G. and Sena, M. M. de C. C. de (2009) ‘Nutritive and non-nutritive attributes of washed-up seaweeds from the coast of Ceará, Brazil’, *Food Chemistry*, 115(1), 254–259.

Oliveira, R. C., Hammer, P., Guibal, E., Taulemesse, J. and Garcia, O. (2014) ‘Characterization of metal– biomass interactions in the Lanthanum (III) biosorption on *Sargassum sp*. using SEM/EDX, FTIR, and XPS: Preliminary studies’, *Chemical Engineering Journal*, 239, 381–391.

Onundi, Y. B., Mamun, A. A., Khatib, M. F. A. and Ahmed, Y. M. (2010) ‘Adsorption of Copper, Nickel and Lead ions from synthetic semiconductor industrial wastewater by palm shell activated carbon', *International Journal of Environmental Science & Technology*, 7(4), 751–758.

Owamah, H. I. (2014) 'Biosorptive removal of Pb (II) and Cu (II) from wastewater using activated carbon from cassava peels', *Journal of Material Cycles and Waste Management*, 16, 347–358.

Pandya, K. Y., Patel, R. V., Jasrai, R. T. and Brahmbhatt, N. H. (2017) 'Preliminary study on potential of seaweeds in decolorization efficacy of synthetic dyes effluent', *International Journal of Plant, Animal and Environmental Sciences*, 7(1), 59–70.

Pang, C., Liu, Y.-H., Cao, X.-H., Li, M., Huang, G.-L., Hua, R., Wang, C.-X., Liu, Y.-T. and An, X.-F. (2011) 'Biosorption of Uranium (VI) from aqueous solution by dead fungal biomass of *Penicillium citrinum*', *Chemical Engineering Journal*, 170(1), 1–6.

Pap, S., Radonić, J., Trifunović, S., Adamović, D., Mihajlović, I., Miloradov, M. V. and Sekulić, M. T. (2016) 'Evaluation of the adsorption potential of eco-friendly activated carbon prepared from cherry kernels for the removal of Pb^{2+}, Cd^{2+} And Ni^{2+} from aqueous wastes', *Journal of Environmental Management*, 184, 297–306.

Park, D., Yun, Y.-S., Lee, D. S. and Park, J. M. (2011) 'Optimum condition for the removal of Cr (VI) or total Cr using dried leaves of *Pinus densiflora*', *Desalination*, 271(1–3), 309–314.

Paskuliakova, A., Tonry, S. and Touzet, N. (2016) Microalgae isolation and selection for the treatment of landfill leachate. *13th International Conference on Modelling, Monitoring and Management of Water Pollution*. 209(WP 2016), 65–78. doi: 10.2495/WP160071.

Patel, G. G., Doshi, H. V and Thakur, M. C. (2016) 'Biosorption and equilibrium study of copper by marine seaweeds from North West Coast of India', *IOSR Journal of Environmental Science, Toxicology and Food Technology*, 10(7), 54–64.

Patel, I. A. and Desai, H. H. (2014) 'Ammonium removal from landfill leachate by chemical precipitation', *International Journal of Innovative Research & Development*, 3(7), 116–126.

PEMANDU (2015). *Solid waste management lab 2015*, Malaysia: Government Transformation Programme. Available at:

https://www.kpkt.gov.my/resources/index/user_1/Attachments/hebahan_slider/slaid_dapatan_makmal.pdf (Accessed: 22 March 2019).

Perez-Marin, A. B., Zapata, V. M., Ortuno, J. F., Aguilar, M., Saez, J. and Llorens, M. (2007) 'Removal of cadmium from aqueous solutions by adsorption onto orange waste', *Journal of Hazardous Materials*, 139(1), 122–131.

Phang, H.-K., Chu, C.-M., Kumaresan, S., Rahman, M. M. and Yasir, S. M. (2015) 'Preliminary study of seaweed drying under a shade and in a natural draft solar dryer', *International Journal of Science and Engineering*, 8(1), 10–14.

Phang, S., Shaharuddin, S., Noraishah, H. and Sasekumar, A. (1996) 'Studies on *Gracilaria changii* (Gracilariales, Rhodophyta) from Malaysian mangroves', *Hydrobiologia*, 326/327, 347–352.

Pinto, J., Henriques, B., Soares, J., Costa, M., Dias, M., Fabre, E., Lopes, C. B., Vale, C., Pinheiro-Torres, J. and Pereira, E. (2020) 'A green method based on living macroalgae for the removal of rare-earth elements from contaminated waters', *Journal of Environmental Management*, 263, 1–11.

Poblete, R., Oller, I., Maldonado, M. I. and Luna, Y. (2017) 'Cost estimation of COD and color removal from landfill leachate using combined coffee-waste based activated carbon with advanced oxidation processes', *Journal of Environmental Chemical Engineering*, 5(1), 114–121.

Podder, M. S. and Majumder, C. B. (2016) 'Study of the kinetics of arsenic removal from wastewater using *Bacillus arsenicus* biofilms supported on a neem leaves/$MnFe_2O_4$ composite', *Ecological Engineering*, 88, 195–216.

Pons, M. P. and Fusté, M. C. (1993) 'Uranium uptake by immobilized cells of *Pseudomonas* strain EPS 5028', *Applied Microbiology and Biotechnology*, 39, 661–665.

Poo, K.-M., Son, E.-B., Chang, J.-S., Ren, X., Choi, Y. J. and Chae, K.-J. (2018) 'Biochars derived from wasted marine macro-algae (*Saccharina japonica* and *Sargassum fusiforme*) and their potential for heavy metal removal in aqueous solution', *Journal of Environmental Management*, 206, 364–372.

Pradhan, D., Sukla, L. B., Mishra, B. B. and Devi, N. (2019) 'Biosorption for removal of hexavalent chromium using microalgae *Scenedesmus sp.*', *Journal of Cleaner Production*, 209, 617–629.

Praveen, R. S. and Vijayaraghavan, K. (2015) ‘Optimization of Cu (II), Ni (II), Cd (II) and Pb (II) biosorption by red marine alga *Kappaphycus alvarezii*’, *Desalination and Water Treatment*, 55(7), 1816–1824.

Qiu, H., Lv, L., Pan, B.-C., Zhang, Q.-J., Zhang, W.-M. and Zhang, Q.-X. (2009) ‘Critical review in adsorption kinetic models’, *Journal of Zhejiang University: Science A*, 10(5), 716–724.

Rahman, M. S. and Sathasivam, K. V. (2016) ‘Heavy metal biosorption potential of a Malaysian rhodophyte (*Eucheuma denticulatum*) from aqueous solutions’, *International Journal of Environmental Science and Technology*, 13, 1973–1988. doi: 10.1007/s13762-016-1022-3.

Rahman, M. S. and Sathasivam, K. V. (2015) ‘Heavy metal adsorption onto *Kappaphycus sp*. from aqueous solutions: The use of error functions for validation of isotherm and kinetics models’, *BioMed Research International*, 2015(Article ID 126298), 1–13. doi: 10.1155/2015/126298.

Rabi'atul Adawiyah Binti Abd Rahman (2016) *Bioremediation of Jeram Sanitary Landfill Leachate Using Selected Potential Bacteria*. Master Thesis, University of Malaya, Kuala Lumpur.

Raisi, S. A. H. A., Sulaiman, H., Suliman, F. E. and Abdallah, O. (2014) ‘Assessment of heavy metals in leachate of an unlined landfill in the Sultanate of Oman’, *International Journal of Environmental Science and Development*, 5(1), 60–63.

Rangabhashiyam, S. and Balasubramanian, P. (2018) ‘Biosorption of hexavalent chromium and malachite green from aqueous effluents, using *Cladophora sp*.’, *Chemistry and Ecology*, 34(4), 371–390.

Rangabhashiyam, S., Suganya, E., Lity, A. V. and Selvaraju, N. (2016) ‘Equilibrium and kinetics studies of hexavalent chromium biosorption on a novel green macroalgae’, *Research on Chemical Intermediates*, 42, 1275–1294.

Ranjan, D., Talat, M. and Hasan, S. H. (2009) ‘Biosorption of arsenic from aqueous solution using agricultural residue “rice polish”’, *Journal of Hazardous Materials*, 166(2–3), 1050–1059.

Rathinam, A., Maharshi, B., Janardhanan, S. K., Jonnalagadda, R. R. and Nair, B. U. (2010) ‘Biosorption of cadmium metal ion from simulated wastewaters using *Hypnea valentiae* biomass: A kinetic and thermodynamic study’, *Bioresource Technology*, 101(5), 1466–1470.

Rathod, M., Mody, K. and Basha, S. (2014) 'Efficient removal of phosphate from aqueous solutions by red seaweed, *Kappaphycus alverezii*', *Journal of Cleaner Production*, 84, 484–493.

Reis, C. E. R., Loures, C. C. A., Castro, H. F. de, Rós, P. C. M. D., Santos, J. C. da, Filho, H. J. I. and Silva, M. B. (2016) 'Microalgae assisted bioremediation of landfill leachate using a biocoil reactor: Evaluation of operational conditions using Taguchi Experimental Design', *British Journal of Environment & Climate Change*, 6(4), 299–308.

Rezaei, H. (2016) 'Biosorption of chromium by using *Spirulina sp*.', *Arabian Journal of Chemistry*, 846–853.

Rhein-Knudsen, N., Ale, M. T., Ajalloueian, F., Yu, L. and Meyer, A. S. (2017) 'Rheological properties of agar and carrageenan from Ghanaian red seaweeds', *Food Hydrocolloids*, 63, 50–58.

Richards, R. G. and Mullins, B. J. (2013) 'Using microalgae for combined lipid production and heavy metal removal from leachate', *Ecological Modelling*, 249, 59–67.

Roberts, D. A. and Nys, R. de (2016) 'The effects of feedstock pre-treatment and pyrolysis temperature on the production of biochar from the green seaweed *Ulva*', *Journal of Environmental Management*, 169, 253–260.

Romera, E., González, F., Ballester, A., Blázquez, M. L. and Muñoz, J. A. (2007) 'Comparative study of biosorption of heavy metals using different types of algae', *Bioresource Technology*, 98(17), 3344–3353.

Ross, A. B., Anastasakis, K., Kubacki, M. and Jones, J. M. (2009) 'Investigation of the pyrolysis behaviour of brown algae before and after pre-treatment using PY-GC/MS and TGA', *Journal of Analytical and Applied Pyrolysis*, 85, 3–10.

Sadaf, S. and Bhatti, H. N. (2014) 'Batch and fixed bed column studies for the removal of indosol yellow BG dye by peanut husk', *Journal of the Taiwan Institute of Chemical Engineers*, 541–553.

Safinaz, A. F. and Ragaa, A. H. (2013) 'Effect of some red marine algae as biofertilizers on growth of maize (*Zea mayz* L.) plants', *International Food Research Journal*, 20(4), 1629–1632.

Salanne, M., Rotenberg, B., Naoi, K., Kaneko, K., Taberna, P.-L., Grey, C. P., Dunn, B. and Simon, P. (2016) 'Efficient storage mechanisms for building better supercapacitors', *Nature Energy*, 1, 1–10.

Saleem, M., Wongsrisujarit, N. and Boonyarattanakalin, S. (2016) ‘Removal of Nickel (II) ion by adsorption on coconut copra meal biosorbent’, *Desalination and Water Treatment*, 57(12), 5623–5635.

Samarghandi, M. R., Hadi, M. and McKay, G. (2014) ‘Breakthrough curve analysis for fixed-bed adsorption of azo dyes using novel pine cone-derived active carbon’, *Adsorption Science and Technology*, 32(10), 791–806.

Santos, R. W. dos, Schmidt, É. C., Felix, M. R. de L., Polo, L. K., Kreusch, M., Pereira, D. T., Costa, G. B., Simioni, C., Chow, F., Ramlov, F., Maraschin, M. and Bouzon, Z. L. (2014) ‘Bioabsorption of cadmium, copper and lead by the red macroalga *Gelidium floridanum*: Physiological responses and ultrastructure features’, *Ecotoxicology and Environmental Safety*, 105, 80–89.

Santos, S. C. R., Ungureanu, G., Volf, I., Boaventura, R. A. R. and Botelho, C. M. S. (2018) 'Chapter 3: Macroalgae biomass as sorbent for metal ions', in Popa, V. and Volf, I. (eds) *Biomass as renewable raw material to obtain bioproducts of high-tech value*. Oxford: Elsevier, B. V., pp. 69-112.

Santoso, J., Gunji, S., Yoshie-Stark, Y. and Suzuki, T. (2006) ‘Mineral contents of Indonesian seaweeds and mineral solubility affected by basic cooking’, *Food Science and Technology Research*, 12(1), 59–66.

Sarada, B., Prasad, M. K., Kumar, K. K. and Murthy, C. V. R. (2014) ‘Cadmium removal by macro algae *Caulerpa fastigiata*: Characterization, kinetic, isotherm and thermodynamic studies’, *Journal of Environmental Chemical Engineering*, 2(3), 1533–1542.

Sari, A. and Tuzen, M. (2008a) ‘Biosorption of Cadmium (II) from aqueous solution by red algae (*Ceramium virgatum*): Equilibrium, kinetic and thermodynamic studies’, *Journal of Hazardous Materials*, 157(2–3), 448–454.

Sari, A. and Tuzen, M. (2008b) ‘Biosorption of Pb (II) and Cd (II) from aqueous solution using green alga (*Ulva lactuca*) Biomass’, *Journal of Hazardous Materials*, 152(1), 302–308.

Sari, A. and Tuzen, M. (2009) ‘Biosorption of As (III) and As (V) from aqueous solution by macrofungus (*Inonotus hispidus*) biomass: Equilibrium and kinetic studies’, *Journal of Hazardous Materials*, 164(2–3), 1372–1378.

Sari, A., Uluozlü, Ö. D. and Tüzen, M. (2011) ‘Equilibrium, Thermodynamic and kinetic investigations on biosorption of arsenic from aqueous solution by algae

(*Maugeotia genuflexa*) biomass', *Chemical Engineering Journal*, 167(1), 155–161.

Sasidharan, S., Darah, I. and JainNoordin, M. K. M. (2010) 'In vitro antimicrobial activity against *Pseudomonas aeruginosa* and acute oral toxicity of marine algae *Gracilaria changii*', *New Biotechnology*, 27(4), 390–396.

Schmid, M., Kraft, L. G. K., Loos, L. M. van der, Kraft, G. T., Virtue, P., Nichols, P. D. and Hurd, C. L. (2018) 'Southern Australian seaweeds: A promising resource for omega-3 fatty acids', *Food Chemistry*, 265, 70–77.

Seghetta, M., Tørring, D., Bruhn, A. and Thomsen, M. (2016) 'Bioextraction potential of seaweed in Denmark-An instrument for circular nutrient management', *Science of the Total Environment*, 563–564, 513–529.

Selvam, G. G. and Sivakumar, K. (2014) 'Influence of seaweed extract as an organic fertilizer on the growth and yield of *Arachis hypogea* L. and their elemental composition using SEM-Energy Dispersive Spectroscopic Analysis', *Asian Pacific Journal of Reproduction*, 3(1), 18–22.

Selvam, S. B., Chelliapan, S., Din, M. F. M., Kamyab, H., Albati, S. K., Othman, N., Yuzir, A. and Nasri, N. S. (2019) 'Landfill leachate treatment by an anaerobic process enhanced with Recyclable Uniform Beads (RUB) of seaweed species of *Gracilaria*', *Desalination and Water Treatment*, 143, 208–216.

Selvam, S. B., Chelliapan, S., Din, M. F. M., Shahperi, R. and Aris, M. A. M. (2016) 'Adsorption of heavy metals from matured leachate by *Gracilaria sp*. extract', *Research Journal of Pharmaceutical, Biological and Chemical Sciences*, 7(3), 15–20.

Semerjian, L. (2018) 'Removal of heavy metals (Cu, Pb) from aqueous solutions using pine (*Pinus halepensis*) sawdust: Equilibrium, kinetic, and thermodynamic studies', *Environmental Technology & Innovation*, 12, 91–103.

Shafique, U., Ijaz, A., Salman, M., Zaman, W. uz, Jamil, N., Rehman, R. and Javaid, A. (2012) 'Removal of arsenic from water using pine leaves', *Journal of the Taiwan Institute of Chemical Engineers*, 43(2), 256–263.

Shama, S. A., Moustafa, M. E. and Gad, M. A. (2010) 'Removal of heavy metals Fe^{3+}, Cu^{2+}, Zn^{2+}, Pb^{2+}, Cr^{3+} and Cd^{2+} from aqueous solutions by using *Eichhornia crassipes*', *Portugaliae Electrochimica Acta*, 28(2), 125–133.

Sharma, V. K. and Sohn, M. (2009) 'Aquatic arsenic: Toxicity, speciation, transformations, and remediation', *Environment International*, 35, 743–759.

Sheng, P. X., Ting, Y.-P., Chen, J. P. and Hong, L. (2004) 'Sorption of lead, copper, cadmium, zinc, and nickel by marine algal biomass: Characterization of biosorptive capacity and investigation of mechanisms', *Journal of Colloid and Interface Science*, 275(1), 131–141.

Shi, X., Leong, K. Y. and Ng, H. Y. (2017) 'Anaerobic treatment of pharmaceutical wastewater: A critical review', *Bioresource Technology*, 245(Part A), 1238–1244.

Shin, W.-S. and Kim, Y.-K. (2014) 'Biosorption characteristics of heavy metals (Ni^{2+}, Zn^{2+}, Cd^{2+}, Pb^{2+}) from aqueous solution by *Hizikia fusiformis*', *Environmental Earth Sciences*, 71, 4107–4114.

Shrestha, B., Kour, J. and Ghimire, K. N. (2016) 'Adsorptive removal of heavy metals from aqueous solution with environmental friendly material—Exhausted tea leaves', *Advances in Chemical Engineering and Science*, 6(4), 525–540.

Sibi, G. (2016) 'Biosorption of chromium from electroplating and galvanizing industrial effluents under extreme conditions using *Chlorella vulgaris*', *Green Energy and Environment*, 1(2), 172–177.

Simonič, M. (2017) 'Compost leachate treatment using polyaluminium chloride and nanofiltration', *Open Chemistry*, 15(1), 123–128.

Singh, S. K., Dixit, K. and Sundaram, S. (2014) 'Effect of acidic and basic pretreatment of wild algal biomass on Cr (VI) biosorption', *Journal of Environmental Science, Toxicology and Food Technology*, 8(5), 38–41.

Sivakumar, D. (2015) 'Hexavalent chromium removal in a tannery industry wastewater using rice husk silica', *Global Journal of Environmental Science and Management*, 1(1), 27–40.

Sizirici, B. and Yildiz, I. (2017) 'Adsorption capacity of iron oxide-coated gravel for landfill leachate: Simultaneous study', *International Journal of Environmental Science and Technology*, 14(5), 1027–1036.

Smedley, P. L. and Kinniburgh, D. G. (2002) 'A review of the source, behaviour and distribution of arsenic in natural waters', *Applied Geochemistry*, 17, 517–568.

Soliman, N. K., Mohamed, H. S., Ahmed, S. A., Sayed, F. H., Elghandour, A. H. and Ahmed, S. A. (2019a) 'Cd^{2+} and Cu^{2+} removal by the waste of the marine brown macroalga *Hydroclathrus clathratus*', *Environmental Technology & Innovation*, 15, 1–19.

Soliman, N. K., Moustafa, A. F., Aboud, A. A. and Halim, K. S. A. (2019b) 'Effective utilization of moringa seeds waste as a new green environmental adsorbent for removal of industrial toxic dyes', *Journal of Materials Research and Technology*, 8(2), 1798–1808.

Solomon, F. (2008). Impacts of metals on aquatic ecosystems and human health. *Research Works*, April, 14–19.

Sounthararajah, D. P., Loganathan, P., Kandasamy, J. and Vigneswaran, S. (2015) 'Adsorptive removal of heavy metals from water using sodium titanate nanofibres loaded onto GAC in fixed-bed columns', *Journal of Hazardous Materials*, 287, 306–316.

Souza, F. B. de, Brandão, H. de L., Hackbarth, F. V., Souza, A. A. U. de, Boaventura, R. A. R., Souza, S. M. A. G. U. de and Vilar, V. J. P. (2016) 'Marine macro-alga *Sargassum cymosum* as electron donor for hexavalent chromium reduction to trivalent state in aqueous solutions', *Chemical Engineering Journal*, 283, 903–910.

Souza, F. B. de, Souza, S. M. A. G. U. de, Souza, A. A. U. de, Costa, C. A. E., Botelho, C. M. S., Vilar, V. J. P. and Boaventura, R. A. R. (2013) 'Modeling of trivalent chromium speciation in binding sites of marine macroalgae *Sargassum cymosum*', *Clean Technologies and Environmental Policy*, 15(6), 987–997.

Storelli, M. M., Storelli, A., D'Addabbo, R., Marano, C., Bruno, R. and Marcotrigiano, G. O. (2005) 'Trace elements in loggerhead turtles (*Caretta caretta*) from The Eastern Mediterranean Sea: Overview and evaluation', *Environmental Pollution*, 135(1), 163–170.

Sulaymon, A. H., Mohammed, A. A. and Al-Musawi, T. J. (2013) 'Competitive biosorption of lead, cadmium, copper, and arsenic ions using algae', *Environmental Science and Pollution Research*, 20, 3011–3023.

Sunil, B. M., Shrihari, S. and Nayak, S. (2009) 'Shear strength characteristics and chemical characteristics of leachate-contaminated lateritic soil', *Engineering Geology*, 106(1–2), 20–25.

Tabaraki, R. and Nateghi, A. (2014) 'Multimetal biosorption modeling of Zn^{2+}, Cu^{2+} and Ni^{2+} by *Sargassum ilicifolium*', *Ecological Engineering*, 197–205.

Tabaraki, R., Nateghi, A. and Ahmady-Asbchin, S. (2014) 'Biosorption of Lead (II) ions on *Sargassum ilicifolium*: Application of Response Surface

Methodology', *International Biodeterioration & Biodegradation*, 93, 145–152.

Tabassum, M. R., Wall, D. M. and Murphy, J. D. (2016) 'Biogas production generated through continuous digestion of natural and cultivated seaweeds with dairy slurry', *Bioresource Technology*, 219, 228–238.

Tabassum, M. R., Xia, A. and Murphy, J. D. (2018) 'Biomethane production from various segments of brown seaweed', *Energy Conversion and Management*, 174, 855–862.

Taffarel, S. R. and Rubio, J. (2009) 'On the removal of Mn^{2+} ions by adsorption onto natural and activated chilean zeolites', *Minerals Engineering*, 22(4), 336–343.

Tan, S. T., Ho, W. S., Hashim, H., Lee, C. T., Taib, M. R. and Ho, C. S. (2015) 'Energy, Economic and Environmental (3E) analysis of Waste-to-Energy (WTE) strategies for Municipal Solid Waste (MSW) Management in Malaysia', *Energy Conversion and Management*, 102, 111–120.

Tee, P. F., Abdullah, M. O., Tan, I. A. W., Rashid, N. K. A., Amin, M. A. M., Nolasco-Hipolito, C. and Bujang, K. (2016) 'Review on hybrid energy systems for wastewater treatment and bio-energy production', *Renewable and Sustainable Energy Reviews*, 54, 235–246.

Tesfagiorgis, K., Navarro, A. E., Chen, B. M., Herrera, N., Hernandez, J., González-Álvarez, Á. and Savane, O. S. (2020) 'Simulations of breakthrough curves for fixed-bed column adsorption of Cobalt (II) ions on spent tealeaves', *Water Science and Technology*, 81(11), 2410–2421.

Tolian, G., Jafari, S. A. and Zarei, S. (2015) 'Optimization of biosorption of Nickel (II) and Cadmium (II) by indigenous seaweed *Enteromorpha* using Response Surface Methodology', *Water Quality Research Journal of Canada*, 50(2), 109–122.

Torres, E., Mera, R., Herrero, C. and Abalde, J. (2014) 'Isotherm studies for the determination of Cd (II) ions removal capacity in living biomass of a microalga with high tolerance to cadmium toxicity', *Environmental Science and Pollution Research*, 21, 12616–12628.

Torretta, V., Ferronato, N., Katsoyiannis, I. A., Tolkou, A. K. and Airoldi, M. (2017) 'Novel and conventional technologies for landfill leachates treatment: A review', *Sustainability*, 9(9), 1–39.

Tounsadi, H., Khalidi, A., Abdennouri, M. and Barka, N. (2015) 'Biosorption Potential of *Diplotaxis harra* and *Glebionis coronaria* L. biomasses for the removal of Cd (II) and Co (II) from aqueous solutions', *Journal of Environmental Chemical Engineering*, 3(2), 822–830.

Tsai, W.-T. (2002) 'A review of environmental hazards and adsorption recovery of cleaning solvent hydrochlorofluorocarbons (HCFCs)', *Journal of Loss Prevention in the Process Industries*, 15(2), 147–157.

Tsai, W.-T. and Chen, H.-R. (2010) 'Removal of malachite green from aqueous solution using low-cost *Chlorell*a-based biomass', *Journal of Hazardous Materials*, 175(1–3), 844–849.

Tsuji, J. S., Perez, V., Garry, M. R. and Alexander, D. D. (2014) 'Association of low-level arsenic exposure in drinking water with cardiovascular disease: A systematic review and risk assessment', *Toxicology*, 323, 78–94.

Tuzen, M., Sari, A., Mendil, D., Uluozlu, O. D., Soylak, M. and Dogan, M. (2009) 'Characterization of biosorption process of As (III) on green algae *Ulothrix cylindricum*', *Journal of Hazardous Materials*, 165(1–3), 566–572.

Ungureanu, G., Santos, S., Boaventura, R. and Botelho, C. (2015) 'Biosorption of antimony by brown algae *S. muticum* and *A. nodosum*', *Environmental Engineering and Management Journal*, 14(2), 455–463.

Uribe, E., Vega-Gálvez, A., García, V., Pastén, A., López, J. and Goñi, G. (2019) 'Effect of different drying methods on phytochemical content and amino acid and fatty acid profiles of the green seaweed, *Ulva spp*.', *Journal of Applied Phycology*, 31, 1967–1979.

Vafajoo, L., Cheraghi, R., Dabbagh, R. and McKay, G. (2018) 'Removal of Cobalt (II) ions from aqueous solutions utilizing the pre-treated *2-Hypnea Valentiae* algae: Equilibrium, thermodynamic, and dynamic studies', *Chemical Engineering Journal*, 331, 39–47.

Verma, A., Kumar, S. and Kumar, S. (2016) 'Biosorption of lead ions from the aqueous solution by *Sargassum filipendula*: Equilibrium and kinetic studies', *Journal of Environmental Chemical Engineering*, 4, 4587–4599.

Vieira, D. M., Costa, A. C. A. da, Henriques, C. A., Cardoso, V. L. and França, F. P. de (2007) 'Biosorption of lead by the brown seaweed *Sargassum filipendula*-Batch and continuous pilot studies', *Electronic Journal of Biotechnology*, 10(3), 368–375.

Vijayaraghavan, J., Pushpa, T. B., Basha, S. J. S., Vijayaraghavan, K. and Jegan, J. (2015) 'Evaluation of red marine alga *Kappaphycus alvarezii* as biosorbent for methylene blue: Isotherm, kinetic, and mechanism studies', *Separation Science and Technology*, 50(8), 1120–1126.

Vijayaraghavan, K. and Balasubramanian, R. (2011) 'Antimonite removal using marine algal species', *Industrial & Engineering Chemistry Research*, 50(17), 9864–9869.

Vijayaraghavan, K., Rangabhashiyam, S., Ashokkumar, T. and Arockiaraj, J. (2017) 'Assessment of samarium biosorption from aqueous solution by brown macroalga *Turbinaria conoides*', *Journal of the Taiwan Institute of Chemical Engineers*, 74, 113–120.

Wang, S., Wang, Q., Hu, Y. M., Xu, S. N., He, Z. X. and Ji, H. S. (2015a) 'Study on the synergistic co-pyrolysis behaviors of mixed rice husk and two types of seaweed by a combined TG-FTIR technique', *Journal of Analytical and Applied Pyrolysis*, 114, 109–118.

Wang, S., Gao, B., Zimmerman, A. R., Li, Y., Ma, L., Harris, W. G. and Migliaccio, K. W. (2015b) 'Removal of arsenic by magnetic biochar prepared from pinewood and natural hematite', *Bioresource Technology*, 175, 391–395.

Wang, X.-S. and Qin, Y. (2005) 'Equilibrium sorption isotherms for of Cu^{2+} on rice bran', *Process Biochemistry*, 40(2), 677–680.

Wang, X. S. and Li, Z. Z. (2009) 'Competitive adsorption of Nickel and Copper ions from aqueous solution using nonliving biomass of the marine brown alga *Laminaria japonica*', *Clean - Soil, Air, Water*, 37(8), 663–668.

White, W. L. and Wilson, P. (2015) 'Chapter 2: World seaweed utilization', in Tiwari, B. K. and Troy, D. J. (eds) *Seaweed sustainability: Food and non-food applications*. San Diego: Academic Press, pp. 7–25.

Wouthuyzen, S., Herandarudewi, S. M. C. and Komatsu, T. (2016) Stock assessment of brown seaweeds (Phaeophyceae) along the Bitung-Bentena Coast, North Sulawesi Province, Indonesia for alginate product using satellite remote sensing. *Procedia Environmental Sciences: The 2nd International Symposium on LAPAN-IPB Satelite for Food Security and Environmental Monitoring 2015, LISAT-FSEM 2015*. 33, 553–561.

Xie, S., Ma, Y., Strong, P. J. and Clarke, W. P. (2015) 'Fluctuation of dissolved heavy metal concentrations in the leachate from anaerobic digestion of municipal solid waste in commercial scale landfill bioreactors: The effect of pH and associated mechanisms’, *Journal of Hazardous Materials*, 299, 577–583.

Yadav, L. S., Mishra, B. K., Kumar, A. and Paul, K. K. (2014) ‘Arsenic removal using bagasse fly ash-iron coated and sponge iron char’, *Journal of Environmental Chemical Engineering*, 2(3), 1467–1473.

Yalçin, S. (2014) ‘The mechanism of heavy metal biosorption on green marine macroalga *Enteromorpha linza*’, *Clean - Soil, Air, Water*, 42(3), 251–259.

Yanyan, L., Kurniawan, T. A., Zhu, M., Ouyang, T., Avtar, R., Othman, M. H. D., Mohammad, B. T. and Albadarin, A. B. (2018) ‘Removal of acetaminophen from synthetic wastewater in a fixed-bed column adsorption using low-cost coconut shell waste pretreated with NaOH, HNO_3, ozone, and/or chitosan’, *Journal of Environmental Management*, 226(April), 365–376.

Yargiç, A. S., Şahin, R. Z. Y., Özbay, N. and Önal, E. (2015) ‘Assessment of toxic Copper(II) biosorption from aqueous solution by chemically-treated tomato waste (*Solanum lycopersicum*)’, *Journal of Cleaner Production*, 88, 152–159.

Yong, Z. J., Bashir, M. J. K., Ng, C. A., Sethupathi, S. and Lim, J.-W. (2018) ‘A sequential treatment of intermediate tropical landfill leachate using a Sequencing Batch Reactor (SBR) and coagulation’, *Journal of Environmental Management*, 205, 244–252.

Yusuf, M., Chuah, L., Khan, M. A. and Choong, T. S. Y. (2014) ‘Adsorption of nickel on electric arc furnace slag: Batch and column studies’, *Separation Science and Technology*, 49(3), 388–397.

Yusuf, M., Song, K. and Li, L. (2020) ‘Fixed bed column and artificial neural network model to predict heavy metals adsorption dynamic on surfactant decorated graphene’, *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 585, 1–15.

Yusuff, A. S., Popoola, L. T. and Babatunde, E. O. (2019) ‘Adsorption of cadmium ion from aqueous solutions by copper-based metal organic framework: Equilibrium Modeling and Kinetic Studies’, *Applied Water Science*, 9(4), 1–11.

Zakaria, N. (2014) 'Detailed EIA for the proposed expansion of 130.55 acres sanitary landfill in mukim Jeram, district of Kuala Selangor, Selangor Darul Ehsan', i-xxxvi.

Zakaria, S. N. F. and Aziz, H. A. (2017) Influence of dosage, pH and contact time in stabilized landfill leachate treatment using ozone/zirconium tetrachloride catalytic oxidation. *Proceedings of the International Conference of Global Network for Innovative Technology and AWAM International Conference in Civil Engineering*. 040030, 1–7.

Zamora-Villafranco, E., Barceló-Quintal, I., Vega-Paz, A., Solís-Correa, H., Méndez-Novelo, R. and Giacomán-Vallejos, G. (2016) 'Leachate treatment by fenton oxidation and adsorption on eggshell and activated carbon', *British Journal of Applied Science & Technology*, 17(2), 1–18.

Zamri, M. F. M. A., Kamaruddin, M. A., Yusoff, M. S., Aziz, H. A. and Foo, K. Y. (2017) 'Semi-aerobic stabilized landfill leachate treatment by ion exchange resin: Isotherm and kinetic study', *Applied Water Science*, 7, 581–590.

Zanella, O., Tessaro, I. C. and Féris, L. A. (2014) 'Desorption- and decomposition-based techniques for the regeneration of activated carbon', *Chemical Engineering and Technology*, 37(9), 1447–1459.

Zanin, E., Scapinello, J., Oliveira, M. de, Rambo, C. L., Franscescon, F., Freitas, L., Mello, J. M. M. de, Fiori, M. A., Oliveira, J. V. and Magro, J. D. (2017) 'Adsorption of heavy metals from wastewater graphic industry using clinoptilolite zeolite as adsorbent', *Process Safety and Environmental Protection*, 105, 194–200.

Zhang, H., Tang, Y., Cai, D., Liu, X., Wang, X., Huang, Q. and Yu, Z. (2010) 'Hexavalent chromium removal from aqueous solution by algal bloom residue derived activated carbon: Equilibrium and kinetic studies', *Journal of Hazardous Materials*, 181(1–3), 801–808.

Zhang, L., Zeng, Y. and Cheng, Z. (2016) 'Removal of heavy metal ions using chitosan and modified chitosan: A review', *Journal of Molecular Liquids*, 214, 175–191.

Zhang, W., Yang, P., Xiao, P., Xu, S., Liu, Y., Liu, F. and Wang, D. (2015) 'Dynamic variation in physicochemical properties of activated sludge floc from different WWTPs and its influence on sludge dewaterability and settleability', *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 467, 124–134.

Zhang, Y., Zhao, J., Jiang, Z., Shan, D. and Lu, Y. (2014) 'Biosorption of Fe (II) and Mn (II) ions from aqueous solution by rice husk ash', *BioMed Research International*, 2014, 1–10.

Zhao, X., Zhou, Y., Huang, S., Qiu, D., Schideman, L., Chai, X. and Zhao, Y. (2014) 'Characterization of microalgae-bacteria consortium cultured in landfill leachate for carbon fixation and lipid production', *Bioresource Technology*, 156, 322–328.

Zin, N. S. M., Aziz, H. A., Adlan, M. N., Ariffin, A., Yusoff, M. S. and Dahlan, I. (2014) 'Treatability study of partially stabilized leachate by composite coagulant (Prehydrolyzed iron and tapioca flour)', *International Journal of Scientific Research in Knowledge*, 2(7), 313–319.

Zwain, H. M., Vakili, M. and Dahlan, I. (2014) 'Waste material adsorbents for zinc removal from wastewater: A comprehensive review', *International Journal of Chemical Engineering*, 1–13.

APPENDIX A

Calculation for stock solution preparation is as shown below.

1. Fe^{2+} solution preparation from Iron (II) sulphate heptahydrate ($FeSO_4.7H_2O$)

Volume of stock solution to prepare = 1 L

Concentration of stock solution to prepare = 100 mg/L

Molecular weight of $FeSO_4.7H_2O$

= 55.845 + 32.06 + (4 X 16.000) + 7[(2 X 1.008) + 16.000] g/mole

= 278.017 g/mole

No. of moles	=	$\frac{mass\ of\ substance\ (g)}{mass\ of\ 1\ mole\ (\frac{g}{mole})}$
No. of moles in 100mg Fe^{2+}	=	$\frac{\left(\frac{100}{1000}\right)(g)}{55.845\ (\frac{g}{mole})}$
	=	0.001791 moles

To prepare a specific volume of a specific molar solution from a dry reagent:

$\frac{Mass\ (g)}{Desired\ volume\ (L)}$	=	Desired molarity (mole/L)	X	Molecular weight (g/mole)		
Mass (g)	=	Desired molarity (mole/L)	X	Molecular weight (g/mole)	X	Desired volume (L)
Mass of $FeSO_4.7H_2O$ (g)	=	0.001791 mole/L	X	278.017 g/mole	X	1 L
	=	0.4979 g				

Therefore, 100 mg/L Fe^{2+} solution was prepared by dissolving 0.4979 g of $FeSO_4.7H_2O$ in deionised water and the volume was made to the mark 1 L volumetric flask using deionised water.

2. Cr^{6+} solution preparation from Potassium dichromate ($K_2Cr_2O_7$)

Volume of stock solution to prepare = 1 L

Concentration of stock solution to prepare = 100 mg/L

Molecular weight of $K_2Cr_2O_7$

= (2 X 39.098) + (2 X 51.996) + (7 X 16.000) g/mole
= 294.188 g/mole

No. of moles	=	$\frac{mass\ of\ substance\ (g)}{mass\ of\ 1\ mole\ (\frac{g}{mole})}$
No. of moles in 100mg Cr^{6+}	=	$\frac{\left(\frac{100}{1000}\right)(g)}{(2\ x\ 51.996)\ (\frac{g}{mole})}$
	=	0.00096 moles

To prepare a specific volume of a specific molar solution from a dry reagent:

$\frac{Mass\ (g)}{Desired\ volume\ (L)}$	=	Desired molarity (mole/L)	X	Molecular weight (g/mole)		
Mass (g)	=	Desired molarity (mole/L)	X	Molecular weight (g/mole)	X	Desired volume (L)
Mass of $K_2Cr_2O_7$ (g)	=	0.00096 mole/L	X	294.188 g/mole	X	1 L
	=	0.2824 g				

Therefore, 100 mg/L Cr^{6+} solution was prepared by dissolving 0.2824 g of $K_2Cr_2O_7$ in deionised water and the volume was made to the mark 1 L volumetric flask using deionised water.

3. As^{5+} solution preparation from Sodium arsenate dibasic heptahydrate ($HAsNa_2O_4.7H_2O$)

Volume of stock solution to prepare = 1 L
Concentration of stock solution to prepare = 100 mg/L
Molecular weight of $HAsNa_2O_4.7H_2O$
= 1.008 + 74.922 + (2 X 22.990) + (4 X 16.000) + 7[(2 X 1.008) + 16.000] g/mole
= 312.022 g/mole

No. of moles	=	$\frac{mass\ of\ substance\ (g)}{mass\ of\ 1\ mole\ (\frac{g}{mole})}$
No. of moles in 100mg As^{5+}	=	$\frac{\left(\frac{100}{1000}\right)(g)}{74.922\ (\frac{g}{mole})}$
	=	0.001335 moles

To prepare a specific volume of a specific molar solution from a dry reagent:

$\frac{Mass\ (g)}{Desired\ volume\ (L)}$	=	Desired molarity (mole/L)	X	Molecular weight (g/mole)		
Mass (g)	=	Desired molarity (mole/L)	X	Molecular weight (g/mole)	X	Desired volume (L)
Mass of $HAsNa_2O_4.7H_2O$ (g)	=	0.001335 mole/L	X	312.022 g/mole	X	1 L
	=	0.4165 g				

Therefore, 100 mg/L As^{5+} solution was prepared by dissolving 0.4165 g of $HAsNa_2O_4.7H_2O$ in deionised water and the volume was made to the mark 1 L volumetric flask using deionised water.

4. Cd^{2+} solution preparation from Cadmium nitrate tetrahydrate ($Cd(NO_3)_2.4H_2O$)

Volume of stock solution to prepare = 1 L

Concentration of stock solution to prepare = 100 mg/L

Molecular weight of $Cd(NO_3)_2.4H_2O$

= 112.41 + 2[14.007 + (3 X 16.000)] + 4[(2 X 1.008) + 16.000] g/mole

= 308.488 g/mole

No. of moles	=	$\frac{mass\ of\ substance\ (g)}{mass\ of\ 1\ mole\ (\frac{g}{mole})}$
No. of moles in 100mg Cd^{2+}	=	$\frac{\left(\frac{100}{1000}\right)(g)}{112.41\ (\frac{g}{mole})}$
	=	0.0008896 moles

To prepare a specific volume of a specific molar solution from a dry reagent:

$\frac{Mass\ (g)}{Desired\ volume\ (L)}$	=	Desired molarity (mole/L)	X	Molecular weight (g/mole)		
Mass (g)	=	Desired molarity (mole/L)	X	Molecular weight (g/mole)	X	Desired volume (L)
Mass of $Cd(NO_3)_2.4H_2O$ (g)	=	0.0008896 mole/L	X	308.488 g/mole	X	1 L
	=	0.2744 g				

Therefore, 100 mg/L Cd^{2+} solution was prepared by dissolving 0.2744 g of $Cd(NO_3)_2.4H_2O$ in deionised water and the volume was made to the mark 1 L volumetric flask using deionised water.

5. Ni^{2+} solution preparation from Nickel (II) nitrate hexahydrate ($Ni(NO_3)_2.6H_2O$)

Volume of stock solution to prepare = 1 L

Concentration of stock solution to prepare = 100 mg/L

Molecular weight of $Ni(NO_3)_2.6H_2O$

= 58.693 + 2[14.007 + (3 X 16.000)] + 6[(2 X 1.008) + 16.000] g/mole

= 290.803 g/mole

No. of moles $= \dfrac{mass\ of\ substance\ (g)}{mass\ of\ 1\ mole\ (\frac{g}{mole})}$

No. of moles in 100mg Ni^{2+} $= \dfrac{\left(\frac{100}{1000}\right)(g)}{58.693\ (\frac{g}{mole})}$

= 0.001704 moles

To prepare a specific volume of a specific molar solution from a dry reagent:

$\dfrac{Mass\ (g)}{Desired\ volume\ (L)}$	=	Desired molarity (mole/L)	X	Molecular weight (g/mole)			
Mass (g)	=	Desired molarity (mole/L)	X	Molecular weight (g/mole)	X	Desired volume (L)
Mass of $Ni(NO_3)_2.6H_2O$ (g)	=	0.001704 mole/L	X	290.803 g/mole	X	1 L
	=	0.4955 g				

Therefore, 100 mg/L Ni^{2+} solution was prepared by dissolving 0.4955 g of $Ni(NO_3)_2.6H_2O$ in deionised water and the volume was made to the mark 1 L volumetric flask using deionised water.

APPENDIX B

The stock solution further diluted to prepare required concentration of heavy metal solution before adding into the landfill leachate. Example of calculation for one heavy metal solution is as shown below and the rest of the heavy metal's concentration prepared accordingly using the same method.

To prepare 20mg/L of Fe^{2+} solution from 100mg/L stock solution, dilution formulae used:

$$V_1C_1 = V_2C_2$$

Where V_1 = Volume of the stock solution

C_1 = Concentration of the stock solution

V_2 = Volume of the final solution

C_2 = Final concentration of the solution

In this case, C_1 = 100mg/L

V_1 = Unknown

V_2 = 100mL

C_2 = 20mg/L

Therefore, V_1 X 100mg/L = 100mL X 20mg/L

V_1 = 20mL

Hence, 20mg/L of Fe^{2+} solution prepared by adding 20mL of Fe^{2+} stock solution into a beaker and distilled water filled up to 100mL.

APPENDIX C

Different set-up mode of the continuous fixed-bed treatment column:

(A) Alternate arrangements of seaweed and fine silicone sand; (B) Seaweed layered between two-third of fine silicone sand portion; (C) Equally mixed seaweed and fine silicone sand; (D) Half seaweed and half fine silicone sand

APPENDIX D

Results of treatment performance of *Gracilaria changii* biosorbent in continuous fixed-column using combination of 50% fine silicone sand and 50% *Gracilaria changii* biosorbent:

Heavy Metals	Feed (mg/L)	Time (hr)											
		1	**3**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**	**22**	**24**
Ni^{2+}	60.0	39.50	34.80	28.00	23.60	20.10	15.50	15.20	12.90	7.74	2.46	0.21	ND (<0.02)
Fe^{2+}	60.0	49.30	43.50	31.20	27.20	25.70	20.60	16.50	11.11	8.03	1.22	0.65	0.30
Cr^{6+}	60.0	31.90	27.90	23.70	18.20	13.10	12.00	10.50	5.84	1.36	1.28	0.07	0.04
Cd^{2+}	60.0	18.80	15.10	9.00	8.30	6.10	5.90	4.90	3.40	1.00	0.17	0.14	0.02
As^{5+}	60.0	28.60	28.30	27.10	25.70	22.60	20.30	15.10	11.60	3.40	1.98	0.92	0.48

*ND: Not Detected

APPENDIX E

International Journal of
Environmental Research and Public Health

MDPI

Review

Treatment of Wastewater Using Seaweed: A Review

Nithiya Arumugam [1], Shreeshivadasan Chelliapan [1,*], Hesam Kamyab [1], Sathiabama Thirugnana [1], Norazli Othman [1] and Noor Shawal Nasri [2]

1 Department of Engineering, Razak Faculty of Technology and Informatics, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, Kuala Lumpur 54100, Malaysia; nithiya85.a@gmail.com (N.A.); hesam_kamyab@yahoo.com (H.K.); sathiabama@utm.my (S.T.); norazli.kl@utm.my (N.O.)

2 Sustainable Waste-To-Wealth, UTM-MPRC Institute for Oil & Gas, Resource Sustainability Research Alliance, Universiti Teknologi Malaysia, Johor Bahru, Johor 81310, Malaysia; noorshaw@utm.my

* Correspondence: shreeshivadasan.kl@utm.my

Received: 26 November 2018; Accepted: 10 December 2018; Published: 13 December 2018

check for updates

Abstract: Inadequately treated or untreated wastewater greatly contribute to the release of unwanted toxic contaminants into water bodies. Some of these contaminants are persistent and bioaccumulative, becoming a great concern as they are released into the environment. Despite the abundance of wastewater treatment technologies, the adsorption method overall has proven to be an excellent way to treat wastewater from multiple industry sources. Because of its significant benefits, i.e., easy availability, handling, and higher efficiency with a low cost relative to other treatments, adsorption is opted as the best method to be used. However, biosorption using naturally found seaweeds has been proven to have promising results in removing pollutants, such as dyes from textile, paper, and the printing industry, nitrogen, and phosphorous and phenolic compounds, as well as heavy metals from various sources. Due to its ecofriendly nature together with the availability and inexpensiveness of raw materials, biosorption via seaweed has become an alternative to the existing technologies in removing these pollutants from wastewater effectively. In this article, the use of low-cost adsorbent (seaweed) for the removal of pollutants from wastewater has been reviewed. An extensive table summarises the applicability of seaweed in treating wastewater. Literature reported that the majority of research used simulated wastewater and minor attention has been given to biosorption using seaweed in the treatment of real wastewater.

Keywords: adsorption; biosorption; seaweed; algae; wastewater

1. Introduction

GRACILARIA CHANGII: SEAWEED ADDING VALUE TO HEAVY METALS REMOVAL FROM LEACHATE

Nithiya Arumugam[1*], Shreeshivadasan Chelliapan[1], Zamri Abdul Rahman[2] Sathiabama T. Thirugnana[1], Imran Ahmad[3], Santhana Krishnan[4], Mohd Fadhil Md Din[4]

[1]Department of Engineering, Razak Faculty of Technology and Informatics, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, Kuala Lumpur 54100, MALAYSIA
**nithiya85.a@gmail.com; shreeshivadasan.kl@utm.my; sathiabama@utm.my*
[2]Worldwide Landfills Sdn Bhd, Shah Alam, MALAYSIA
[3]Malaysia Japan International Institute of Technology, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, 54100, Kuala Lumpur, MALAYSIA
mustafwibinqamar@gmail.com
[4]Centre for Environmental Sustainability and Water Security, UTM Sustainability Campus, Department of Environmental Engineering, Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, MALAYSIA

ABSTRACT

Treatment of landfill leachate often involves technologies to reduce toxicity to meet environmental standards prior to discharge into water bodies. The malignant of generating landfill leachate primarily depends on the source of waste dumped at the landfill site. Heavy metals are one of the major pollutants in leachate. Due to their harmful nature towards the ecosystem, specifically, when exceeded the regulatory standards, authorities are in the urge of finding a solution to reduce the severity. In that purpose, many types of treatment methods practised. However, the choice of treatment techniques exclusively depends on the nature and composition of leachate. Adsorption technique has received significant interests and several types of adsorbents being researched. However, alternatives for existing adsorbents are necessary by the fact to replace costly, non-environmental friendly and sophisticated production and operations of adsorbents. Therefore, this paper aims to introduce *Gracilaria changii*, a seaweed species based adsorbent which found abundantly in nature. This adsorbent was used to remove Cr^{6+} and Fe^{2+} from leachate via a laboratory batch study. Leachate with synthetically added heavy metals concentrations of 20, 40, 60, 80 and 100mg/L tested with optimum pH of 5, 10g seaweed dosage and stirrer speed of 50 for time intervals 10-60min. Adsorption of metal ions onto seaweed found to be influenced by contact time and initial concentration of metal ions. In general, the rapid removal occurred in the first 30min, and decreasing removal rate observed after that. It reached maximum removals of 60% and 98% for Cr^{6+} and Fe^{2+} respectively at t=30min and initial concentration of 100mg/L. In conclusion, *Gracilaria changii* potentially an environmental friendly adsorbent in removing Cr^{6+} and Fe^{2+} from leachate.

Environmental Technology & Innovation 17 (2020) 100571

Contents lists available at ScienceDirect

Environmental Technology & Innovation

journal homepage: www.elsevier.com/locate/eti

Bioremediation potential of macroalgae *Gracilaria edulis* and *Gracilaria changii* co-cultured with shrimp wastewater in an outdoor water recirculation system

Saberi Mawi [a,b], Santhana Krishnan [b,*], Mohd Fadhil MD Din [b,*], Nithiya Arumugam [c], Shreeshivadasan Chelliapan [c]

[a] *Brackish Water Aquaculture Research Division, Fisheries Research Institute (FRI), 81550 Gelang Patah, Johor, Malaysia*
[b] *Center of Environmental Sustainability and Water Security (IPASA), Research Institute of Sustainable Environment (RISE), School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia (UTM), 81310 Skudai, Johor, Malaysia*
[c] *Department of Engineering, Razak Faculty of Technology and Informatics, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, Kuala Lumpur, 54100, Malaysia*

ARTICLE INFO

Article history:
Received 27 August 2019
Received in revised form 26 November 2019
Accepted 30 November 2019
Available online 6 December 2019

Keywords:
Gracilaria edulis
Gracilaria changii
Nutrient removal
Shrimp wastewater
Macroalgae
Bioremediation

ABSTRACT

Effluent from the aquaculture industry discharged into water bodies and it impacts the environment severely. The shrimp industry is one of the developing aquacultures that releases a high amount of organic matters in the form of wastewater. As an effort to reduce the environmental impact, an integrated system with shrimp and macroalgae researched abundantly as the macroalgae are naturally capable of removing nutrient from wastewater. As a bioremediation potential, this study investigates the nutrient uptake and macroalgal growth performance in short term (21 days) using an outdoor recirculating water system stocked with two local macroalgae species *Gracilaria edulis* and *Gracilaria changii* as biofilter. The stocking density of 3 kg/m^{2}with the flow rate of the water system set to 200 L/hr during the operation. The temperature, pH, dissolved oxygen (DO) and salinity was measured daily throughout the experimental period. Water temperature in all tanks were almost constant and ranged between 28.5 °C to 29.1 °C. The higher mean of pH of around 8.26 ± 0.15 and 8.28 ± 0.05 was observed in tanks with *G. edulis* and *G. changii* respectively. In the control tanks, mean pH was 7.87 ± 0.09. The mean concentrations of dissolved oxygen in *G. edulis*, *G. changii* and control tanks were 6.89 ± 0.05 mg/L, 6.84 ± 0.06 mg/L, and 6.10 ± 0.03 mg/L respectively. The mean growth rates of *Gracilaria edulis* and *Gracilaria changii* were found to be 4.3% day^{-1}, 4.1% day^{-1} with carbon to nitrogen (C:N) ratio of 8.3 to 8.5 respectively. The removal rate of ammonium and nitrate by the two species were found to be 72.5%, 71.0%, and 58.8%, 56.8% respectively. The macroalgal biofilter is found to be an ecologically sustainable that has improved the shrimp water quality to an acceptable level that in turn ultimately enhanced shrimp and macroalgae productivity.

1. Introduction

CHAPTER 11

Anaerobic treatment of municipal solid waste landfill leachate

Shreeshivadasan Chelliapan[1], Nithiya Arumugam[1], Mohd. Fadhil Md. Din[2], Hesam Kamyab[1] and Shirin Shafiei Ebrahimi[3]

[1]Department of Engineering & Technology, Razak Faculty of Technology and Informatics, Universiti Teknologi Malaysia, Kuala Lumpur, Malaysia

[2]Centre for Environmental Sustainability and Water Security (IPASA), Research Institute for Sustainable Environment (RISE), School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia (UTM), Skudai, Johor, Malaysia

[3]School of Education, Universiti Teknologi Malaysia, Johor Bahru, Malaysia

11.1 Introduction

As the world's population increases daily, which is projected to hit 8.5 billion by 2030, the urge toward urbanization becomes a necessity [1]. The rate of urban waste being produced is rising faster than the rate of urbanization, which is a sign of mankind's growing affluence. The generation of municipal solid waste (MSW) has acquired alarming dimensions globally as the population size increases. Approximately 1.3 billion metric tons of MSW were generated in 2016 globally and it is expected to rise to about 2.2 billion by 2025 [2]. Economic development, the rate of industrialization, the various public practices of different regions, urbanization, and changing consumption patterns are some factors influencing MSW generation.

The expeditious extension of industrial and commercial sectors and enormous consumption of packaged products as a consequence of rising living standards has boosted the generation of solid waste in recent years. The increase in waste volume poses a significant challenge in disposing of the waste in a controlled and sustainable way. A big problem that many governments are trying to solve today is the fast growth of solid and hazardous wastes [3]. Researchers are trying to find the most efficient and sustainable solution for waste management. Despite the effort to divert waste from landfills, landfilling is still the primary method of waste disposal in both developed and developing countries. In spite of enjoying various advantages, one of the disadvantages of this method is the

Bioreactors
DOI: https://doi.org/10.1016/B978-0-12-821264-6.00011-5

Journal of Environmental Treatment Techniques 2020, Volume 8, Issue 3, Pages: 1089-1092

J. Environ. Treat. Tech.
ISSN: 2309-1185

Journal web link: http://www.jett.dormaj.com

Optimisation of Heavy Metals Uptake from Leachate Using Red Seaweed *Gracilaria changii*

Nithiya Arumugam[1*], Shreeshivadasan Chelliapan[1], Sathiabama T. Thirugnana[1] and Aida Batrisyia Jasni[2]

[1]Department of Engineering, Razak Faculty of Technology and Informatics, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, 54100 Kuala Lumpur, Malaysia
[2]School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, Johor Bahru, Malaysia

Received: 28/03/2020 Accepted: 07/07/2020 Published: 20/09/2020

Abstract

Heavy metal is one of the pollutants in landfill leachate besides organic and inorganic pollutants. The presence of heavy metal is alarming due to its harmful nature; makes it incompatible to be discharged into water bodies before treatments. There are many treatment techniques to remove heavy metals from wastewater, where some of them even involve the coupling of one or more techniques to facilitate and improve the removal efficiency. However, the adsorption using seaweed is one of the known techniques to eliminate heavy metals from wastewater efficiently. Therefore, this study introduced a new adsorbent for heavy metal adsorption: red seaweed *Gracilari changii*. The effect of operational parameters such as leachate pH (2-7), seaweed dosage (2-10 g), rpm (10-100), and contact time (10-60 min) on the optimum adsorption of *Gracilaria changii* was studied. At optimum pH (pH=5), seaweed dosage (10g), rpm (rpm=50) and contact time (30min), *Gracilaria changii* showed maximum metal ion removal of 45%, 35%, and 30% for Fe^{2+}, Cr^{6+} and Ni^{2+} respectively. The adsorption was rapid and reached equilibrium after t=30min in general. This optimisation result can be used as a reference to study the effect of different dosages of the adsorbent towards the removal rate.

Keywords: Seaweed, Adsorption, Leachate, Heavy metals, Adsorbent

1 Introduction

Leachate is the dark form of liquid generated via percolation of rainwater through dumping of solid wastes into landfills. Rainwater undergoes biochemical processes with wastes and also with the water contents of the waste itself (1). Random studies showed that $0.2m^3$ of leachate are generated from every one metric ton of municipal solid waste (2). The qualities and quantities of leachate vary from one site to another depending on factors: moisture content, landfill age, climate, site hydrology, and the degree of waste stabilisation (3).

Leachates are a mixture of colour components, heavy metals, ammoniacal nitrogen, organic compounds, and inorganic compounds (4,5). Among these, heavy metals are the most toxic compounds and draw great attention due to their negative impact towards both living organisms and the environment as a whole (6). The presence of heavy metals in leachate are sourced from adopted for the treatment of leachate: biological, physical, chemical, and physico-chemical techniques. Nevertheless, the preference of a technique or coupling of techniques is solely based on the characteristics of leachate (13). Lately, the removal of heavy metals by adsorption method using various types of adsorbents received great interests, with seaweed being one of them. Seaweeds are macroalges and consists of 10,000 naturally existing species. These seaweeds can vary in size and typically grow up to 30 meters in length. Although seaweed has plant-like physical structure and components, they are not genuine vascular plants, but are referred as marine algae. Marine algae belongs to the Kingdom Protista group, which by default are neither plants nor animals.

There are three different groups of seaweeds and they are identified based on the colour of their thallus namely brown, green, and red algae. A number of studies show that different

LIST OF PUBLICATIONS

Journal with Impact Factor

1. **Arumugam, N**., Chelliapan, S., Kamyab, H., Thirugnana, S., Othman, N., & Nasri, N. S. (2018). Treatment of wastewater using seaweed: A review. *International Journal of Environmental Research and Public Health*, *15*(12), 1-17. https://doi.org/10.3390/ijerph15122851. **(Q2, IF: 2.849)**
2. Mawi, S., Krishnan, S., Din, M. F. M., **Arumugam, N**., & Chelliapan, S. (2020). Bioremediation potential of macroalgae *Gracilaria edulis* and *Gracilaria changii* co-cultured with shrimp wastewater in an outdoor water recirculation system. *Environmental Technology & Innovation*, *17*, 1-8. https://doi.org/10.1016/j.eti.2019.100571. **(Q2, IF: 3.356)**

Indexed Journal

1. **Arumugam, N**., Chelliapan, S., Thirugnana, S. T., & Jasni, A. B. (2020). Optimisation of heavy metals uptake from leachate using red seaweed *Gracilaria changii*. *Journal of Environmental Treatment Techniques*, *8*(3), 1089-1092. **(Indexed by SCOPUS)**

Non-Indexed Conference Proceedings

1. **Arumugam, N**., Chelliapan, S., Rahman, Z. A., Thirugnana, S. T., Ahmad, I., Krishnan, S., & Din, M. F. M. (2019). *Gracilaria changii*: Seaweed adding value to heavy metals removal from leachate. In *International Conference on Environmental Sustainability and Resource Security, 2019 (IC-ENSURES 2019)* (pp. 183-188).

Book Chapter

1. Chelliapan, S., **Arumugam, N**., Din, M. F. M., Kamyab, H. & Ebrahimi, S. S. (2020) *Chapter 11: Anaerobic treatment of municipal solid waste landfill leachate*, in Singh, L., Yousuf, A. & Mahapatra, D. M. (eds) Bioreactors: Sustainable design and industrial applications in mitigation of GHG emissions. Oxford: Elsevier, pp. 175-1