UNIVERSITI PUTRA MALAYSIA

ENHANCEMENT OF PRIMARY TREATMENT PROCESS FOR DOMESTIC WASTEWATER USING TANNIN-BASED COAGULANT

YASIR TALIB HAMEED

FK 2018 27

ENHANCEMENT OF PRIMARY TREATMENT PROCESS FOR DOMESTIC WASTEWATER USING TANNIN-BASED COAGULANT

By

YASIR TALIB HAMEED

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

November 2017

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

ENHANCEMENT OF PRIMARY TREATMENT PROCESS FOR DOMESTIC WASTEWATER USING TANNIN-BASED COAGULANT

By

YASIR TALIB HAMEED

November 2017

Chairman : Professor Azni Idris, PhD
Faculty : Engineering

Coagulation and flocculation as a pre-treatment before biological process is one of the options to enhance the treated water quality and drive possible savings in the construction and operation of treatment plants.

The common coagulants such as Al^{3+} and Fe^{3+} have been used extensively for long time. However, they are known to act as an additional burden to the environment. Furthermore, there is a public health risk from the use of Al^{3+}. Because of that, great efforts have been made to provide environmentally friendly alternatives to conventional coagulants and flocculants. One of these alternatives is a tannin-based coagulant and flocculant with the name Tanfloc.

The aim of this study was to improve the performance of a biofilm process by pre-treating the wastewater using Tanfloc and to study the effect of extended use of Tanfloc on the microbial community of the biofilm.

To achieve these objectives, a five-stage experiment was conducted. In the first stage, chemical characteristics of Tanfloc were determined using FTIR and EDX in addition to determination of Tanfloc biodegradability. Moreover, jar test experiments were conducted to compare the performance of Tanfloc to Polyaluminium chloride (PAC). In the second stage, a preliminary study was conducted on Tanfloc performance in a continuous flow experiment using only flocculation and sedimentation units. In the third stage, the biofilm unit in the continuous flow experiment was run and Tanfloc effects were evaluated on the three units. Flocculation process was evaluated by studying floc size and residual turbidity. Primary clarifier was evaluated by

determining the removal efficiencies. Finally, aeration tank was evaluated by studying treatment efficiency and dissolved oxygen level. When third stage has finished, results were analysed and they were not clear to show the effect of Tanfloc. Consequently, fourth stage using a smaller aeration tank has been decided to be conducted. In the fifth stage, the effect of Tanfloc on the biofilm community was investigated in a specific study of biofilm characteristics. Effect of Tanfloc on the percentage of bacterial genera was studied in addition to substrate concentration and dissolved oxygen.

The outcomes of the first stage showed that Tanfloc can compete with PAC as a flocculant. While Tanfloc achieved 85%, 60% and 64% removal efficiencies for TSS, BOD_5 and COD, the efficiencies were 64%, 55% and 55% for PAC. The improvement in floc size for Tanfloc compared to PAC improved turbidity removal, Tanfloc removed 70% of the turbidity within only 2 minutes, compared to 42% for PAC. The outcomes of the third and fourth stage showed that even at short flocculation time (7.5 min), Tanfloc showed a high potential to form big flocs with a size distribution of d (10), d (50) and d (90) of 18, 42 and 96 micron. Enhancement of the clarification process due to Tanfloc application was very clear and while the efficiency of TSS removal in the clarifier was only 4% at a flow of 18 L/min (HRT = 55.5 min), with Tanfloc it achieved a 60% efficiency. Even at a high flow of 26 L/min (HRT= 39 min), a removal efficiency of 31% was achieved when Tanfloc was applied. An enhancement in aeration tank performance was noticed due to Tanfloc's effect on reducing the organic load; the BOD_5 for the treated water dropped from the range of 24 – 50 to the range of 7–24 mg/L when Tanfloc was introduced. Moreover, the dissolved oxygen level in the aeration tank jumped almost to double the value when Tanfloc was introduced to the biological process. An interesting point in the results of the fifth stage is the ammonia nitrogen removal. In the experiment without Tanfloc, there was a complete inhibition of ammonia nitrogen removal at retention time of 4 hours, while Tanfloc produced a removal efficiency of around 70% of the ammonia nitrogen at the same retention time (4 hours). Biofilm community analysis showed a significant increment in the percentage of *Nitrosomonas* and *Nitrospira* genera in the biofilm cultured by flocculated water (3.33% and 7.8% respectively) compared to the biofilm cultured by raw wastewater (0.073% and 0.19 % respectively). This increase justified and confirmed the aforementioned improvement in ammonia nitrogen removal in the experiment with Tanfloc.

The aforementioned results suggest Tanfloc as a promising agent to enhance the performance of clarification and biological treatment units and consequently reduce the required volumes of treatment units and saving energy. In light of this enhancement, Tanfloc could be used to upgrade the existing treatment plants or design compact treatment units.

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

PENAMBAHBAIKAN PROSES RAWATAN PRIMER UNTUK AIR SISA DOMESTIK MENGGUNAKAN KOAGULAN BERASASKAN TANNIN

Oleh

YASIR TALIB HAMEED

November 2017

Pengerusi : Profesor Azni Idris, PhD
Fakulti : Kejuruteraan

Pembekuan dan pemberbukuan sebagai pra-rawatan dalam proses biologikal ialah salah satu pilihan untuk menambah baik kualiti air terawat dan penjimatan dalam pembinaan dan operasi loji rawatan.

Koagulan konvensional seperti Al^{3+} dan Fe^{3+} telah digunakan secara meluas untuk jangka masa yang lama. Akan tetapi, unsur-unsur ini diketahui menyumbang kepada beban tambahan terhadap alam sekitar. Oleh kerana itu, banyak usaha telah dibuat untuk menyediakan alternatif kepada koagulan dan flokulan konvensional yang lebih mesra alam. Salah satu yang menjadi pilihan adalah koagulan dan flokulan berasaskan tannin di bawah nama Tanfloc.

Tujuan kajian ini ialah untuk meningkatkan prestasi proses biofilem melalui pra-rawatan air sisa dengan menggunakan Tanfloc dan juga mengkaji kesan lanjutan penggunaan Tanfloc terhadap komuniti mikrobial biofilem.

Untuk mencapai objektif-objektif ini, satu eksperimen lima peringkat telah dijalankan. Dalam peringkat pertama, ciri-ciri kimia untuk Tanfloc telah ditentukan melalui FTIR dan EDX sebagai tambahan kepada penentuan tahap biodegradasi Tanfloc. Tambahan pula, eksperimen ujian balang telah dijalankan untuk membandingkan kecekapan Tanfloc berbanding Polialuminium klorida (PAC). Dalam peringkat kedua,satu kajian awal telah dilakukan terhadap kecekapan Tanfloc dalam loji pandu dengan hanya menggunakan unit pemberbukuan dan pemendapan. Dalam peringkat ketiga, unit biofilem di dalam loji pandu telah dijalankan dan kesan-kesan Tanfloc terhadap loji pandu telah dinilai. Proses pemberbukuan telah dinilai melalui penelitian terhadap saiz

flok dan saki-baki kekeruhan. Penjernih primer telah dinilai berdasarkan kecekapan penyingkiran. Pada akhirnya, tangki pengudaraan telah dikaji melalui kecekapan rawatan dan paras oksigen terlarut. Apabila peringkat ketiga telah selesai, hasil-hasil kajian telah dianalisis dan ianya masih tidak jelas untuk menunjukkan kesan Tanfloc. Bertitik tolak daripada itu, peringkat keempat dengan menggunakan tangki pengudaraan yang lebih kecil telah diputuskan untuk dijalankan. Dalam peringkat kelima, kesan Tanfloc terhadap komuniti biofilem telah dikaji dalam eksperimen berskala kecil. Kesan Tanfloc terhadap peratusan genera bakteria telah dikaji sebagai tambahan kepada kepekatan substrat dan oksigen terlarut.

Hasil daripada peringkat pertama menunjukkan Tanfloc menyaingi PAC sebagai flokulan. Ketika Tanfloc mencapai 85%, 60% dan 64% kecekapan penyingkiran untuk TSS, BOD_5 dan COD, kecekapannya ialah 64%, 55% dan 55% untuk PAC. Peningkatan saiz flok dengan mengggunakan Tanfloc berbanding PAC meningkatkan penyingkiran kekeruhan. Tanfloc menyingkirkan 70% daripada kekeruhan dalam masa hanya 2 minit, berbanding 33% untuk PAC. Hasil-hasil kajian peringkat ketiga dan keempat menunjukkan bahawa walaupun pada masa pemberbukuan yang singkat (7.5 min), Tanfloc berpotensi besar untuk membentuk flok yang besar dengan taburan saiz d (10), d (50) dan d (90) dengan nilai 18, 42 dan 96 mikron. Penambahbaikan proses penjernihan melalui aplikasi Tanfloc adalah sangat jelas. Biarpun kecekapan penyingkiran TSS di dalam penjernih ialah hanya 4% pada kadar aliran 18 L/min (HRT = 55.5 min), 60% berjaya dicapai apabila Tanfloc digunakan. Walaupun pada kadar aliran yang tinggi pada 26 L/min (HRT = 39 min), 31% kecekapan penyingkiran telah dicapai apabila Tanfloc digunakan. Penambahbaikan dalam prestasi tangki pengudaraan telah dikesan hasil daripada kesan Tanfloc terhadap pengurangan beban organik, BOD_5 untuk air terawat jatuh daripada julat 24 – 50 kepada julat 7 – 24 mg/L apabila Tanfloc digunakan. Tambahan pula, paras oksigen terlarut di dalam tangki pengudaraan menginjak naik hampir dua kali ganda (ia mencecah had 6 mg/L) apabila Tanfloc digunakan dalam proses biologikal. Apa yang menarik dalam hasil peringkat kelima ialah data dalam penyingkiran ammonia nitrogen. Dalam eksperimen tanpa Tanfloc, terdapat perencatan sepenuhnya terhadap penyingkiran ammonia pada masa tahanan 4 jam, sedangkan kecekapan penyingkiran ammonia nitrogen telah mencapai 70% pada masa tahanan yang sama (4 jam). Analisis komuniti biofilem menunjukkan kenaikan ketara dalam peratusan *Nitrosomonas* dan *Nitrospira* genera di dalam biofilem dibiakkan melalui air yang berbuku (masing-masing 3.33% dan 7.8%) berbanding biofilem dibiakkan melalui air sisa mentah (masing-masing 0.073% dan 0.19%). Kenaikan ini mewajarkan dan mengesahkan peningkatan dalam penyingkiran ammonia nitrogen dalam eksperimen dengan Tanfloc seperti dinyatakan di atas.

Hasil-hasil kajian yang dinyatakan di atas mencadangkan Tanfloc sebagai ejen berpotensi untuk meningkatkan prestasi unit penjernihan dan rawatan biologikal serta mengurangkan isipadu yang diperlukan untuk unit rawatan dan menjimatkan tenaga. Berdasarkan penambahbaikan ini, Tanfloc boleh digunakan untuk menaik taraf loji rawatan sedia ada atau unit rawatan bereka bentuk kompak.

ACKNOWLEDGEMENTS

" IN THE NAME OF ALLAH THE MOST GRACIOUS MOST MERCIFUL"

All prises and thanks to almighty ALLAH for giving me the opportunity to complete this work.

My deepest gratitude and sincere appreciation is owed to my supervisor prof. Dr. Azni Idris for his invaluable guidance, continuous support and encouragement from the beginning until the end of this study. I would like to express my appreciation to Dr. Siti Aslina Hussain, Dr. Norhafizah Abdullah and Dr. Hasfalina Che Man for their valuable time and precious advices during the course of this study.

Special thanks are due to the Universiti Putra Malaysia for supporting this research especially the staff of Chemical and Environmental Engineering. I wish to thank with true gratitude my friends and labmates for their friendship, cooperation and support.

My deepest gratitude is owed to my family for their cooperation, patience and support.

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

Azni Bin Idris, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Siti Aslina bt. Hussain, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Norhafizah bt. Abdullah, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software

Signature: _____ Date: _____

Name and Matric No.: Yasir Talib Hameed , GS 37584

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) were adhered to.

Signature:	_____
Name of Chairman of Supervisory Committee:	Professor Dr. Azni Bin Idris
Signature:	_____
Name of Member of Supervisory Committee:	Associate Professor Dr. Siti Aslina bt. Hussain
Signature:	_____
Name of Member of Supervisory Committee:	Associate Professor Dr. Norhafizah bt. Abdullah

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AOB	Ammonia Oxidizing Bacteria
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
C/N	Carbon / Nitrogen ratio
d (10)	The size that 10%, of total volume of flocs was below this value
d (50)	The size that 50%, of total volume of flocs was below this value
d (90)	The size that 90%, of total volume of flocs was below this value
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
EDX	Energy-Dispersive X-ray Spectroscopy
FT-IR	Fourier-Transform Infrared Spectroscopy
HRT	Hydraulic Retention Time
KDa	Kilodalton
NGS	Next Generation Sequencing
NOB	Nitrite Oxidizing Bacteria
NTU	Nephelometric Turbidity Unit
OLR	Organic Loading Rate
PAC	Polyaluminium chloride
PCR	Polymerase Chain Reaction
PE	Population Equivalent
PFS	Polyferric sulphate
POME	Palm Oil Mill Effluent
QIIME	Quantitative Insights Into Microbial Ecology

SVI	Sludge Volume Index
TDS	Total Dissolved Solids
THMs	Trihalomethanes
TOC	Total Organic Carbon
TP	Total Phosphate
TSS	Total Suspended Solids
UV 254	Ultraviolet absorption at 254 nm
VSS	Volatile Suspended Solids
μ s/ cm	Micro Siemens / cm

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter introduces the background of wastewater treatment plants and common modifications that respond to changes in both water quality and quantity. The problem statement focuses on current interests and concerns about the treatment process; especially those related to the use of coagulation and flocculation processes, in addition to conventional and new materials utilized for that purpose. The objectives are determined and the scope of the study is elaborated upon in Chapter One.

1.2 Research Background

Water supply is one of the most important requirements of life. In human societies, most of the water supplied will eventually be converted into domestic wastewater. If this wastewater is not treated, it will accumulate and become anaerobic (due to a lack of dissolved oxygen), and consequently, it will be considered a terrible source of nuisance for the community.

For this reason, wastewater treatment is a main feature of urban areas. Treatment plants are comprised of sequencing steps of physical, chemical and biological processes that interact together to decrease wastewater pollution to a required level. Concerns about the treatment of wastewater started at the beginning of the last century. At that time, the objectives of treatment were limited to removing solids and biodegradable organics, and the elimination of pathogenic organisms. As the concerns about pollution and its effect on public health and the environment increased, the standards of treated water quality became more stringent and previous treatment processes were deemed to be insufficient to respond to these standards (Wang et al., 2015). Consequently, new processes and methods were introduced into this field (Fulazzaky et al., 2015; Leyva-Díaz et al., 2015a; Martín-Pascual et al., 2016; Wang et al., 2014).

One of the optional chemical processes, which are used in wastewater treatment plants to improve treatment efficiency, is the coagulation and flocculation process. Wastewater contains solids in a variety of size distributions. A certain proportion are colloids, which are, due to their small size, infeasible to be settled by gravity. As a practical solution, these colloids can be forced to agglomerate by coagulation and flocculation, in order to grow big enough to be removed physically (Suopajärvi et al., 2013). A variety of materials (inorganics and organics), show a superior potential to function as coagulants and flocculants (Aljuboori et al., 2013; Aljuboori et al., 2014; Choudhary et al., 2015; Liu et al., 2016).

However, the treatment of wastewater should not act as an additional source of pollution. In other words, sludge generated from the wastewater treatment process should be environmentally friendly as much as possible. A high percentage of the sludge produced from conventional treatment is biodegradable, and the rest is mainly dust, sand and other particles (Qasim, 1998). Regardless of the high requirement for funds and the necessary skills to manage this type of sludge, it is still feasible (Qasim, 1998); compared to the sludge produced from chemical treatments, like precipitation and coagulation, using metal ions (Choy et al., 2014; Lee et al., 2014).

1.3 Problem Statement

Construction of conventional sewage treatment plants is restricted by the availability of large required area, which is considered a major contributor to the high capital cost of the treatment plants. The operation of these plants is extremely energy intensive; for example, water and wastewater utilities consume about 2% according to Dotro et al. (2011) and 3% according to Spellman (2013) of the total amount of electricity produced in the United States. Upgrading the existing treatment plants to cater for the increasing population or to respond to new and more stringent standards is another challenge faced by the authorities due to the difficulties to provide the required land for the extension.

In order to accommodate these issues, several attempts have been conducted to develop and modify conventional treatment units or provide alternative methods with fewer requirements for construction, operation or land. Reducing the influent organic load to the biological unit is a possible approach to reduce the requirements for volume and oxygen supply for this unit. USEPA (2010) stated that oxygen requirement is a reflection of organic load. Practically, enhancing the sedimentation process is one of the alternatives to reduce the influent organic load to the biological unit.

Efficiently designed and operated primary sedimentation tanks should remove from 50 to 70% of the suspended solids and 25 – 40 % of the BOD. This anticipated efficiency is negatively affected by eddy currents formed by the inertia of the incoming fluid, wind induced circulation cells formed in uncovered tanks, thermal convection currents and thermal stratification in hot arid climate. Inclined plates and tube settlers are common modifications to enhance sedimentation process especially in the compact units with limited available space.

Enhancement of sedimentation process could be achieved by preceding the coagulation and flocculation process. Traditional chemical coagulants and flocculants are aluminium and ferrous salts. Several environmental and public health problems arise due to extended use of these conventional chemicals. From a medical point of view, aluminium residuals in alum treated water have been the centre of attention, as they are linked to serious health issues, such as Alzheimer (Lee et al., 2014). From an environmental point of view, a serious drawback of hydrolysing metal coagulants is

the production of large amounts of toxic sludge, which is non-biodegradable due to the nature of the coagulant. Moreover, 99% of alum sludge is made up of water and alum sludge is rather hard to dewater (Lee et al., 2014; Renault et al., 2009) Other drawbacks include large amounts are required for efficient flocculation, it is highly sensitive to pH, inefficient towards very fine particles, inefficient in cold water (especially Polyaluminium chloride), and finally, the presence of aluminium in water negatively affects the disinfection process (Choy et al., 2014; Lee et al., 2014).

Consequently, great efforts have been made to provide natural coagulants as a substitution for conventional inorganic coagulants (Abidin et al., 2013; Aljuboori et al., 2013; Aljuboori et al., 2014; Aljuboori et al., 2015; Amagloh and Benang, 2009; Beltrán-Heredia et al., 2010b; Beltrán-Heredia et al., 2012; Gong et al., 2008; Graham et al., 2008; Li et al., 2009; Lian et al., 2008; Xia et al., 2008a). Meanwhile, several natural coagulants are produced in commercial quantities; others are at the limits of lab scale production.

Introducing these natural coagulants to conventional treatment processes, in the hope of improving performance to accommodate higher flow (upgrade treatment plants for increased population), achieve better treatment efficiency (upgrade treatment plants for new stringent standards) and energy saving, have not been well investigated. For this reason, a tannin based agent (a natural coagulant) was used in this study to enhance the performance of sedimentation process, in the hope of improving the overall treatment efficiency.

1.4 Research Objectives:

This study aims to investigate the improvement of treatment process by introducing Tanfloc (a tannin based coagulant) as a pre-treatment for sewage treatment plants. The specific objectives of this study are as follows:

(i) To assess the potential and effectiveness of applying Tanfloc in domestic wastewater treatment.
(ii) To determine Tanfloc efficiency in a continuous flow experiment using flocculation and sedimentation units only.
(iii) To investigate the effects of Tanfloc to reduce influent organic load to a biofilm treatment unit.
(iv) To characterize the type of microbial community within a biofilm cultured in flocculated wastewater using Tanfloc.

1.5 Scope of the Study

The scope of this study extended to give more details about the characteristics and behaviour of Tanfloc. The investigation includes the chemical characterization of Tanfloc in addition to determination of the best dose and mixing conditions for both Tanfloc and polyaluminium chloride (PAC). The effect of Tanfloc on removal efficiency of pollutants from domestic wastewater was investigated. Furthermore, investigation of floc size and settling velocity of Tanfloc compared to PAC was conducted. The investigation extended to include the study of sludge produced for Tanfloc and PAC. The effect of cations on flocculation performance was evaluated. Moreover, zeta potential measurement was studied.

Preliminary study of Tanfloc performance in the flocculation and sedimentation units in continuous flow experiment was conducted to give more details about Tanfloc behaviour in continuous flow experiment. The experiment proceeded to study the effects of Tanfloc on the treatment process at different flow rates. To evaluate the flocculation process, floc size distribution, sludge volume index and residual turbidity were determined. However, clarifier performance was evaluated by the determination of influent and effluent concentration of COD, BOD, TSS, ammonia nitrogen, turbidity and total phosphate for five different flow rates with and without Tanfloc. Aeration tank performance was evaluated by the determination of COD, BOD, TSS, turbidity, and total phosphate for the influent and effluent for five different flow rates with and without Tanfloc. Moreover, the evaluation of aeration tank included dissolved oxygen study and estimation of secondary sludge production.

The effect of Tanfloc on the biofilm community was evaluated, biofilm samples were taken after the process had stabilized from the two identical reactors (with and without Tanfloc), and tested for illumina Next Generation Sequencing technology (NGS), which is used to identify the species of bacteria and their percentage in a biofilm community. Wastewater characteristics were determined in addition to dissolved oxygen level to have a detailed description of the entire scenario in which the biofilm was cultured.

1.6 Thesis layout

This thesis consists of five chapters. Chapter One explains the background of the study and the problem statement, and ends with stating the objectives and scope of the research. Literature review was covered in Chapter Two including coagulation, flocculation and biofilm treatment process as main topics in the review. In Chapter Three, the materials used in the experiments were listed and explained in details including chemicals and treatment process units. Moreover, details about preparation of samples for the analysis were explained, finally the methods and procedures of conducting the experiments and taking and analyzing the samples were covered also in Chapter Three. Chapter Four presents the results and discussion about Tanfloc and its effect on the sedimentation process and biofilm units, in addition to the effect of

Tanfloc on the biofilm bacterial community. Chapter Five wraps up the thesis with conclusions and recommendations for the future work.

REFERENCES

Abidin, Z.Z., Ismail, N., Yunus, R., Ahamad, I.S., Idris, A., 2011. A preliminary study on Jatropha curcas as coagulant in wastewater treatment. Environmental technology 32(9), 971-977.

Abidin, Z.Z., Shamsudin, N.S.M., Madehi, N., Sobri, S., 2013. Optimisation of a method to extract the active coagulant agent from Jatropha curcas seeds for use in turbidity removal. Industrial Crops and Products 41, 319-323.

Aboulhassan, M., Souabi, S., Yaacoubi, A., Baudu, M., 2016. Coagulation efficacy of a tannin coagulant agent compared to metal salts for paint manufacturing wastewater treatment. Desalination and Water Treatment, 1-7.

Aljuboori, A.H.R., Idris, A., Abdullah, N., Mohamad, R., 2013. Production and characterization of a bioflocculant produced by Aspergillus flavus. Bioresource technology 127, 489-493.

Aljuboori, A.H.R., 2013. production and characterization of a bioflocculant from aspergillus flavus and its application in water treatment Chemical and environmental UPM.

Aljuboori, A.H.R., Uemura, Y., Osman, N.B., Yusup, S., 2014. Production of a bioflocculant from Aspergillus niger using palm oil mill effluent as carbon source. Bioresource technology 171, 66-70.

Aljuboori, A.H.R., Idris, A., Al-joubory, H.H.R., Uemura, Y., Abubakar, B.I., 2015. Flocculation behavior and mechanism of bioflocculant produced by Aspergillus flavus. Journal of environmental management 150, 466-471.

Amagloh, F.K., Benang, A., 2009. Effectiveness of Moringa oleifera seed as coagulant for water purification. African Journal of Agricultural Research 4(1), 119-123.

Amaral-Silva, N., Martins, R.C., Castro-Silva, S., Quinta-Ferreira, R.M., 2016. Ozonation and perozonation on the biodegradability improvement of a landfill leachate. Journal of Environmental Chemical Engineering 4(1), 527-533.

Antov, M.G., Šćiban, M.B., Petrović, N.J., 2010. Proteins from common bean (Phaseolus vulgaris) seed as a natural coagulant for potential application in water turbidity removal. Bioresource technology 101(7), 2167-2172.

Arimi, M.M., Zhang, Y., Namango, S.S., Geißen, S.-U., 2016. Reuse of recalcitrant-rich anaerobic effluent as dilution water after enhancement of biodegradability by Fenton processes. Journal of environmental management 168, 10-15.

Azziz, G., Trasante, T., Monza, J., Irisarri, P., 2016. The effect of soil type, rice cultivar and water management on ammonia-oxidizing archaea and bacteria populations. Applied Soil Ecology 100, 8-17.

Bai, S., Zhu, Y., Zhang, X., Zhang, H., Gong, Y., 2010. Enhanced phosphorus removal from municipal wastewater by coagulation with alum and iron salts, Bioinformatics and Biomedical Engineering (iCBBE), 2010 4th International Conference on. IEEE, pp. 1-4.

Barrado-Moreno, M., Beltrán-Heredia, J., Martín-Gallardo, J., 2016. Removal of Oocystis algae from freshwater by means of tannin-based coagulant. Journal of Applied Phycology 28(3), 1589-1595.

Beltrán-Heredia, J., Sánchez-Martín, J., 2009. Municipal wastewater treatment by modified tannin flocculant agent. Desalination 249(1), 353-358.

Beltrán-Heredia, J., Sánchez-Martín, J., Delgado-Regalado, A., Jurado-Bustos, C., 2009a. Removal of Alizarin Violet 3R (anthraquinonic dye) from aqueous solutions by natural coagulants. Journal of Hazardous Materials 170(1), 43-50.

Beltrán-Heredia, J., Sánchez-Martín, J., Solera-Hernández, C., 2009b. Anionic surfactants removal by natural coagulant/flocculant products. Industrial & Engineering Chemistry Research 48(10), 5085-5092.

Beltrán-Heredia, J., Sánchez-Martín, J., Martín-Sánchez, C., 2010a. Remediation of dye-polluted solutions by a new tannin-based coagulant. Industrial & Engineering Chemistry Research 50(2), 686-693.

Beltrán-Heredia, J., Sánchez-Martín, J., Gómez-Muñoz, M., 2010b. New coagulant agents from tannin extracts: Preliminary optimisation studies. Chemical Engineering Journal 162(3), 1019-1025.

Beltrán-Heredia, J., Sánchez-Martín, J., Dávila-Acedo, M., 2011. Optimization of the synthesis of a new coagulant from a tannin extract. Journal of hazardous materials 186(2), 1704-1712.

Beltrán-Heredia, J., Sánchez-Martín, J., Gómez-Muñoz, C., 2012. Performance and characterization of a new tannin-based coagulant. Applied Water Science 2(3), 199-208.

Benakova, A., Wanner, J., 2013. Application of fluorescence in situ hybridization for the study and characterization of nitrifying bacteria in nitrifying/denitrifying wastewater treatment plants. Environmental technology 34(16), 2415-2422.

Biswas, K., Taylor, M.W., Turner, S.J., 2014. Successional development of biofilms in moving bed biofilm reactor (MBBR) systems treating municipal wastewater. Applied microbiology and biotechnology 98(3), 1429-1440.

Bolto, B., Gregory, J., 2007. Organic polyelectrolytes in water treatment. Water research 41(11), 2301-2324.

Bongiovani, M.C., Camacho, F.P., Coldebella, P.F., Valverde, K.C., Nishi, L., Bergamasco, R., 2015. Removal of natural organic matter and trihalomethane minimization by coagulation/flocculation/filtration using a natural tannin. Desalination and Water Treatment, 1-10.

Chen, H., Zhong, C., Berkhouse, H., Zhang, Y., Lv, Y., Lu, W., Yang, Y., Zhou, J., 2016. Removal of cadmium by bioflocculant produced by Stenotrophomonas maltophilia using phenol-containing wastewater. Chemosphere 155, 163-169.

Chen, S., Sun, D., Chung, J.-S., 2008. Simultaneous removal of COD and ammonium from landfill leachate using an anaerobic–aerobic moving-bed biofilm reactor system. Waste Management 28(2), 339-346.

Choudhary, A.K., Kumar, S., Sharma, C., 2015. Removal of chloro-organics and color from pulp and paper mill wastewater by polyaluminium chloride as coagulant. Desalination and Water Treatment 53(3), 697-708.

Choy, S., Prasad, K., Wu, T., Ramanan, R., 2015. A review on common vegetables and legumes as promising plant-based natural coagulants in water clarification. International Journal of Environmental Science and Technology 12(1), 367-390.

Choy, S.Y., Prasad, K.M.N., Wu, T.Y., Raghunandan, M.E., Ramanan, R.N., 2014. Utilization of plant-based natural coagulants as future alternatives towards sustainable water clarification. Journal of environmental sciences 26(11), 2178-2189.

Choy, S.Y., Prasad, K.M.N., Wu, T.Y., Raghunandan, M.E., Yang, B., Phang, S.-M., Ramanan, R.N., 2016. Isolation, characterization and the potential use of starch from jackfruit seed wastes as a coagulant aid for treatment of turbid water. Environmental Science and Pollution Research, 1-14.

Cydzik-Kwiatkowska, A., Zielińska, M., 2016. Bacterial communities in full-scale wastewater treatment systems. World Journal of Microbiology and Biotechnology 32(4), 1-8.

da Costa Filho, B.M., da Silva, V.M., de Oliveira Silva, J., da Hora Machado, A.E., Trovó, A.G., 2016. Coupling coagulation, flocculation and decantation with photo-Fenton process for treatment of industrial wastewater containing fipronil: Biodegradability and toxicity assessment. Journal of environmental management 174, 71-78.

del Real-Olvera, J., Rustrian-Portilla, E., Houbron, E., Landa-Huerta, F.J., 2016. Adsorption of organic pollutants from slaughterhouse wastewater using powder of Moringa oleifera seeds as a natural coagulant. Desalination and Water Treatment 57(21), 9971-9981.

Dezfooli, S.M., Uversky, V.N., Saleem, M., Baharudin, F.S., Hitam, S.M.S., Bachmann, R.T., 2016. A simplified method for the purification of an intrinsically disordered coagulant protein from defatted Moringa oleifera seeds. Process Biochemistry.

Dharani, M., Balasubramanian, S., 2016. Synthesis, characterization and application of acryloyl chitosan anchored copolymer towards algae flocculation. Carbohydrate Polymers 152, 459-467.

Di Bella, G., Giustra, M., Freni, G., 2014. Optimisation of coagulation/flocculation for pre-treatment of high strength and saline wastewater: Performance analysis with different coagulant doses. Chemical Engineering Journal 254, 283-292.

Dialynas, E., Diamadopoulos, E., 2008. Integration of immersed membrane ultrafiltration with coagulation and activated carbon adsorption for advanced treatment of municipal wastewater. Desalination 230(1), 113-127.

Dong, C., Chen, W., Liu, C., 2014. Flocculation of algal cells by amphoteric chitosan-based flocculant. Bioresource technology 170, 239-247.

Dotro, G., Jefferson, B., Jones, M., Vale, P., Cartmell, E., Stephenson, T., 2011. A review of the impact and potential of intermittent aeration on continuous flow nitrifying activated sludge. Environmental technology 32(15), 1685-1697.

Eaton, A.D., Franson, M.A.H., Association, A.P.H., Association, A.W.W., Federation, W.E., 2005. Standard Methods for the Examination of Water & Wastewater. American Public Health Association.

ECOLEX, 2009. Environmental Quality (Sewage) Regulations, 2009. https://www.ecolex.org/details/legislation/environmental-quality-sewage-regulations-2009-lex-faoc099051/. (Accessed 13 November 2017).

Fast, S.A., Gude, V.G., 2015. Ultrasound-chitosan enhanced flocculation of low algal turbid waters. Journal of Industrial and Engineering Chemistry 24, 153-160.

Fatihah, S., Donnelly, T., 2009. Spatial distribution of ammonia-oxidizing bacteria in the biofilm and suspended growth biomass of the full-and partial-bed biological aerated filters A paper submitted to the Journal of Environmental Engineering and Science. Canadian Journal of Civil Engineering 36(11), 1859-1866.

Felföldi, T., Jurecska, L., Vajna, B., Barkács, K., Makk, J., Cebe, G., Szabó, A., Záray, G., Márialigeti, K., 2015. Texture and type of polymer fiber carrier determine bacterial colonization and biofilm properties in wastewater treatment. Chemical Engineering Journal 264, 824-834.

Freitas, T., Oliveira, V., de Souza, M., Geraldino, H., Almeida, V., Fávaro, S., Garcia, J., 2015. Optimization of coagulation-flocculation process for treatment of industrial textile wastewater using okra (A. esculentus) mucilage as natural coagulant. Industrial Crops and Products 76, 538-544.

Fulazzaky, M.A., Abdullah, N.H., Yusoff, A.R.M., Paul, E., 2015. Conditioning the alternating aerobic–anoxic process to enhance the removal of inorganic nitrogen pollution from a municipal wastewater in France. Journal of Cleaner Production 100, 195-201.

Garcia-Fayos, B., Arnal, J., Ruiz, V., Sancho, M., 2016. Use of Moringa oleifera in drinking water treatment: study of storage conditions and performance of the coagulant extract. Desalination and Water Treatment 57(48-49), 23365-23371.

García-Mesa, J.J., Poyatos, J.M., Delgado, F., Hontoria, E., 2010. The influence of biofilm treatment systems on particle size distribution in three wastewater treatment plants. Water, Air, & Soil Pollution 212(1-4), 37-49.

Ge, S., Wang, S., Yang, X., Qiu, S., Li, B., Peng, Y., 2015. Detection of nitrifiers and evaluation of partial nitrification for wastewater treatment: a review. Chemosphere 140, 85-98.

Ghernaout, D., Ghernaout, B., 2012. Sweep flocculation as a second form of charge neutralisation—a review. Desalination and Water Treatment 44(1-3), 15-28.

Giri, S.S., Harshiny, M., Sen, S.S., Sukumaran, V., Park, S.C., 2015. Production and characterization of a thermostable bioflocculant from Bacillus subtilis F9, isolated from wastewater sludge. Ecotoxicology and environmental safety 121, 45-50.

Gong, W.-X., Wang, S.-G., Sun, X.-F., Liu, X.-W., Yue, Q.-Y., Gao, B.-Y., 2008. Bioflocculant production by culture of Serratia ficaria and its application in wastewater treatment. Bioresource Technology 99(11), 4668-4674.

Gong, Y., Li, J., Zhang, Y., Zhang, M., Tian, X., Wang, A., 2016. Partial degradation of levofloxacin for biodegradability improvement by electro-Fenton process using an activated carbon fiber felt cathode. Journal of hazardous materials 304, 320-328.

Graham, N., Gang, F., Fowler, G., Watts, M., 2008. Characterisation and coagulation performance of a tannin-based cationic polymer: A preliminary assessment. Colloids and surfaces A: Physicochemical and engineering aspects 327(1), 9-16.

Grčić, I., Vrsaljko, D., Katančić, Z., Papić, S., 2015. Purification of household greywater loaded with hair colorants by solar photocatalysis using TiO 2-coated textile fibers coupled flocculation with chitosan. Journal of Water Process Engineering 5, 15-27.

Guida, M., Mattei, M., Della Rocca, C., Melluso, G., Meriç, S., 2007. Optimization of alum-coagulation/flocculation for COD and TSS removal from five municipal wastewater. Desalination 211(1), 113-127.

Hammer, M.J., Hammer Jr, M.J., 2008. Water and Wastewater Technology. Printice-Hall. Inc. Upper Saddle River, NJ.

Hasar, H., Xia, S., Ahn, C.H., Rittmann, B.E., 2008. Simultaneous removal of organic matter and nitrogen compounds by an aerobic/anoxic membrane biofilm reactor. water research 42(15), 4109-4116.

Hendricks, D., 2010. Fundamentals of water treatment unit processes: physical, chemical, and biological. CRC Press.

Heredia, J.B., Martín, J.S., 2009. Removing heavy metals from polluted surface water with a tannin-based flocculant agent. Journal of hazardous materials 165(1), 1215-1218.

Huang, X., Gao, B., Yue, Q., Wang, Y., Li, Q., Zhao, S., Sun, S., 2013. Effect of dosing sequence and raw water pH on coagulation performance and flocs properties using dual-coagulation of polyaluminum chloride and compound bioflocculant in low temperature surface water treatment. Chemical engineering journal 229, 477-483.

Jia, S., Yang, Z., Yang, W., Zhang, T., Zhang, S., Yang, X., Dong, Y., Wu, J., Wang, Y., 2016. Removal of Cu (II) and tetracycline using an aromatic rings-functionalized chitosan-based flocculant: Enhanced interaction between the flocculant and the antibiotic. Chemical Engineering Journal 283, 495-503.

Kamar, W., Saadiah, W.I., Abdul Aziz, H., Ramli, S.F., 2015. Removal of Suspended Solids, Chemical Oxygen Demand and Color from Domestic Wastewater Using Sago Starch as Coagulant, Applied Mechanics and Materials. Trans Tech Publ, pp. 519-524.

Lee, C.S., Robinson, J., Chong, M.F., 2014. A review on application of flocculants in wastewater treatment. Process Safety and Environmental Protection 92(6), 489-508.

Leyva-Díaz, J., González-Martínez, A., Muñío, M., Poyatos, J., 2015a. Two-step nitrification in a pure moving bed biofilm reactor-membrane bioreactor for wastewater treatment: nitrifying and denitrifying microbial populations and kinetic modeling. Applied microbiology and biotechnology 99(23), 10333-10343.

Leyva-Díaz, J., González-Martínez, A., González-López, J., Muñío, M., Poyatos, J., 2015b. Kinetic modeling and microbiological study of two-step nitrification in a membrane bioreactor and hybrid moving bed biofilm reactor–membrane bioreactor for wastewater treatment. Chemical Engineering Journal 259, 692-702.

Li, L., Zhang, H., Pan, G., 2015. Influence of zeta potential on the flocculation of cyanobacteria cells using chitosan modified soil. Journal of Environmental Sciences 28, 47-53.

Li, Y., Xu, Y., Liu, L., Jiang, X., Zhang, K., Zheng, T., Wang, H., 2016. First evidence of bioflocculant from Shinella albus with flocculation activity on harvesting of Chlorella vulgaris biomass. Bioresource Technology 218, 807-815.

Li, Z., Zhong, S., Lei, H.-y., Chen, R.-w., Yu, Q., Li, H.-L., 2009. Production of a novel bioflocculant by Bacilluslicheniformis X14 and its application to low temperature drinking water treatment. Bioresource Technology 100(14), 3650-3656.

Lian, B., Chen, Y., Zhao, J., Teng, H.H., Zhu, L., Yuan, S., 2008. Microbial flocculation by Bacillus mucilaginosus: Applications and mechanisms. Bioresource Technology 99(11), 4825-4831.

Liu, J., Ma, J., Liu, Y., Yang, Y., Yue, D., Wang, H., 2014. Optimized production of a novel bioflocculant M-C11 by Klebsiella sp. and its application in sludge dewatering. Journal of Environmental Sciences 26(10), 2076-2083.

Liu, W., Hao, Y., Jiang, J., Zhu, A., Zhu, J., Dong, Z., 2016. Production of a bioflocculant from Pseudomonas veronii L918 using the hydrolyzate of peanut hull and its application in the treatment of ash-flushing wastewater generated from coal fired power plant. Bioresource Technology 218, 318-325.

Lopez-Lopez, C., Martín-Pascual, J., González-Martínez, A., Calderón, K., González-López, J., Hontoria, E., Poyatos, J., 2012. Influence of filling ratio and carrier type on organic matter removal in a moving bed biofilm reactor with pretreatment of electrocoagulation in wastewater treatment. Journal of Environmental Science and Health, Part A 47(12), 1759-1767.

Martín-Pascual, J., Leyva-Díaz, J.C., Poyatos, J.M., 2016. Treatment of urban wastewater with pure moving bed membrane bioreactor technology at different filling ratios, hydraulic retention times and temperatures. Annals of Microbiology 66(2), 607-613.

Meraz, K.A.S., Vargas, S.M.P., Maldonado, J.T.L., Bravo, J.M.C., Guzman, M.T.O., Maldonado, E.A.L., 2016. Eco-friendly innovation for nejayote coagulation–flocculation process using chitosan: Evaluation through zeta potential measurements. Chemical Engineering Journal 284, 536-542.

Ndikubwimana, T., Zeng, X., Liu, Y., Chang, J.-S., Lu, Y., 2014. Harvesting of microalgae Desmodesmus sp. F51 by bioflocculation with bacterial bioflocculant. Algal Research 6, 186-193.

Niu, J., Kasuga, I., Kurisu, F., Furumai, H., Shigeeda, T., Takahashi, K., 2016. Abundance and diversity of ammonia-oxidizing archaea and bacteria on granular activated carbon and their fates during drinking water purification process. Applied microbiology and biotechnology 100(2), 729-742.

Nwodo, U.U., Green, E., Mabinya, L.V., Okaiyeto, K., Rumbold, K., Obi, L.C., Okoh, A.I., 2014. Bioflocculant production by a consortium of Streptomyces and Cellulomonas species and media optimization via surface response model. Colloids and Surfaces B: Biointerfaces 116, 257-264.

Oladoja, N.A., 2015. Headway on natural polymeric coagulants in water and wastewater treatment operations. Journal of Water Process Engineering 6, 174-192.

Pedros, P., Wang, J., Metghalchi, H., 2007. Single-submerged attached growth bioreactor for simultaneous removal of organics and nitrogen. Journal of Environmental Engineering 133(2), 191-197.

Pittoors, E., Guo, Y., Van Hulle, S.W., 2014. Oxygen transfer model development based on activated sludge and clean water in diffused aerated cylindrical tanks. Chemical Engineering Journal 243, 51-59.

Prodanović, J.M., Antov, M.G., Šćiban, M.B., Ikonić, B.B., Kukić, D.V., Vasić, V.M., Ivetić, D.Ž., 2013. The fractionation of natural coagulant extracted from common bean by use of ultrafiltration membranes. Desalination and Water Treatment 51(1-3), 442-447.

Pu, S.-y., Qin, L.-l., Che, J.-p., Zhang, B.-r., Xu, M., 2014. Preparation and application of a novel bioflocculant by two strains of Rhizopus sp. using potato starch wastewater as nutrilite. Bioresource technology 162, 184-191.

Qasim, S.R., 1998. Wastewater treatment plants: planning, design, and operation. CRC Press.

Ramavandi, B., Farjadfard, S., 2014. Removal of chemical oxygen demand from textile wastewater using a natural coagulant. Korean Journal of Chemical Engineering 31(1), 81-87.

Renault, F., Sancey, B., Badot, P.-M., Crini, G., 2009. Chitosan for coagulation/flocculation processes–an eco-friendly approach. European Polymer Journal 45(5), 1337-1348.

Rodgers, M., Xiao, L., Mulqueen, J., 2007. Horizontal-flow biofilm system with step feed for nitrogen removal. Journal of Environmental Engineering 133(6), 569-574.

Roselet, F., Vandamme, D., Roselet, M., Muylaert, K., Abreu, P.C., 2015. Screening of commercial natural and synthetic cationic polymers for flocculation of freshwater and marine microalgae and effects of molecular weight and charge density. Algal Research 10, 183-188.

Roselet, F., Burkert, J., Abreu, P.C., 2016. Flocculation of Nannochloropsis oculata using a tannin-based polymer: bench scale optimization and pilot scale reproducibility. Biomass and Bioenergy 87, 55-60.

Saminathan, S., Liu, H., Nguyen, T.V., Vigneswaran, S., 2011. Organic matter removal from biologically treated sewage effluent by flocculation and oxidation coupled with flocculation. Desalination and Water Treatment 32(1-3), 133-137.

Sánchez-Martín, J., González-Velasco, M., Beltrán-Heredia, J., 2009. Acacia mearnsii de wild tannin-based flocculant in surface water treatment. Journal of wood chemistry and technology 29(2), 119-135.

Sánchez-Martín, J., Beltrán-Heredia, J., Solera-Hernández, C., 2010a. Surface water and wastewater treatment using a new tannin-based coagulant. Pilot plant trials. Journal of environmental management 91(10), 2051-2058.

Sánchez-Martín, J., González-Velasco, M., Beltrán-Heredia, J., 2010b. Surface water treatment with tannin-based coagulants from Quebracho (Schinopsis balansae). Chemical Engineering Journal 165(3), 851-858.

Sánchez-Martín, J., Beltrán-Heredia, J., Coco-Rivero, B., 2014. New lab-made coagulant based on Schinopsis balansae tannin extract: synthesis optimization and preliminary tests on refractory water pollutants. Applied Water Science 4(3), 261-271.

Sánchez- Martín, J., Beltrán- Heredia, J., Dávila- Acedo, M., 2011. Optimum coagulant from Acacia mearnsii de Wild for wastewater treatment. Chemical Engineering & Technology 34(12), 2069-2076.

Shak, K.P.Y., Wu, T.Y., 2014. Coagulation–flocculation treatment of high-strength agro-industrial wastewater using natural Cassia obtusifolia seed gum: treatment efficiencies and flocs characterization. Chemical Engineering Journal 256, 293-305.

Shen, J.-P., Zhang, L.-M., Di, H.J., He, J.-Z., 2012. A review of ammonia-oxidizing bacteria and archaea in Chinese soils. Frontiers in microbiology 3.

Singh, R., Kumar, S., Garg, M., 2016. Domestic Wastewater Treatment Using Tanfloc: A Tannin Based Coagulant, Geostatistical and Geospatial Approaches for the Characterization of Natural Resources in the Environment. Springer, pp. 349-354.

SPAN, 2016. Malaysian Sewerage Industry Guidelines - MSIG. http://www.span.gov.my/files/MSIG/MSIGVol4/10_Appendix_A.pdf. (Accessed 12 November 2017).

Spellman, F.R., 2010. Spellman's Standard Handbook for Wastewater Operators: Volume I, Fundimental Level. Crc Press.

Spellman, F.R., 2013. Handbook of water and wastewater treatment plant operations. CRC Press.

Subudhi, S., Batta, N., Pathak, M., Bisht, V., Devi, A., Lal, B., 2014. Bioflocculant production and biosorption of zinc and lead by a novel bacterial species, Achromobacter sp. TERI-IASST N, isolated from oil refinery waste. Chemosphere 113, 116-124.

Subudhi, S., Bisht, V., Batta, N., Pathak, M., Devi, A., Lal, B., 2016. Purification and characterization of exopolysaccharide bioflocculant produced by heavy metal resistant Achromobacter xylosoxidans. Carbohydrate polymers 137, 441-451.

Suja, F., Donnelly, T., 2008. Effect of full and partial-bed configuration on carbon removal performance of biological aerated filters. Water Science and Technology 58(5), 977-983.

Suopajärvi, T., Liimatainen, H., Hormi, O., Niinimäki, J., 2013. Coagulation–flocculation treatment of municipal wastewater based on anionized nanocelluloses. Chemical engineering journal 231, 59-67.

Tchobanoglous, G., Burton, F.L., Metcalf, Eddy, Stensel, H.D., 2003. Wastewater Engineering: Treatment and Reuse. McGraw-Hill.

Teh, C.Y., Wu, T.Y., Juan, J.C., 2014. Potential use of rice starch in coagulation–flocculation process of agro-industrial wastewater: treatment performance and flocs characterization. Ecological Engineering 71, 509-519.

Tran, N., Drogui, P., Blais, J.-F., Mercier, G., 2012. Phosphorus removal from spiked municipal wastewater using either electrochemical coagulation or chemical coagulation as tertiary treatment. Separation and purification technology 95, 16-25.

USEPA, 2010. Evaluation Of Energy Conservation Measures For Wastewater Treatment Facilities (EPA 832-R-10-005).

Van Hulle, S.W., Vandeweyer, H.J., Meesschaert, B.D., Vanrolleghem, P.A., Dejans, P., Dumoulin, A., 2010. Engineering aspects and practical application of autotrophic nitrogen removal from nitrogen rich streams. Chemical Engineering Journal 162(1), 1-20.

Wang, W., Chen, S., Bao, K., Gao, J., Zhang, R., Zhang, Z., Sugiura, N., 2014. Enhanced removal of contaminant using the biological film, anoxic–anaerobic–aerobic and electro-coagulation process applied to high-load sewage treatment. Environmental technology 35(7), 833-840.

Wang, X.-H., Wang, X., Huppes, G., Heijungs, R., Ren, N.-Q., 2015. Environmental implications of increasingly stringent sewage discharge standards in municipal wastewater treatment plants: case study of a cool area of China. Journal of Cleaner Production 94, 278-283.

Wang, X.-J., Xia, S.-Q., Chen, L., Zhao, J.-F., Renault, N., Chovelon, J.-M., 2006. Nutrients removal from municipal wastewater by chemical precipitation in a moving bed biofilm reactor. Process Biochemistry 41(4), 824-828.

Xia, S., Zhang, Z., Wang, X., Yang, A., Chen, L., Zhao, J., Leonard, D., Jaffrezic-Renault, N., 2008a. Production and characterization of a bioflocculant by Proteus mirabilis TJ-1. Bioresource technology 99(14), 6520-6527.

Xia, S., Li, J., Wang, R., 2008b. Nitrogen removal performance and microbial community structure dynamics response to carbon nitrogen ratio in a compact suspended carrier biofilm reactor. Ecological Engineering 32(3), 256-262.

Xu, Y., Purton, S., Baganz, F., 2013. Chitosan flocculation to aid the harvesting of the microalga Chlorella sorokiniana. Bioresource technology 129, 296-301.

Yang, K., Li, Z., Zhang, H., Qian, J., Chen, G., 2010. Municipal wastewater phosphorus removal by coagulation. Environmental technology 31(6), 601-609.

Yang, Y., Li, N., Zhao, Q., Yang, M., Wu, Z., Xie, S., Liu, Y., 2016. Ammonia-oxidizing archaea and bacteria in water columns and sediments of a highly eutrophic plateau freshwater lake. Environmental Science and Pollution Research 23(15), 15358-15369.

Yang, Z., Li, H., Yan, H., Wu, H., Yang, H., Wu, Q., Li, H., Li, A., Cheng, R., 2014. Evaluation of a novel chitosan-based flocculant with high flocculation performance, low toxicity and good floc properties. Journal of hazardous materials 276, 480-488.

Yin, Y.-J., Tian, Z.-M., Tang, W., Li, L., Song, L.-Y., McElmurry, S.P., 2014. Production and characterization of high efficiency bioflocculant isolated from Klebsiella sp. ZZ-3. Bioresource technology 171, 336-342.

Yuan, Y., Zhang, H., Pan, G., 2016. Flocculation of cyanobacterial cells using coal fly ash modified chitosan. Water research 97, 11-18.

Zhang, F., Wang, Y., Chu, Y., Gao, B., Yue, Q., Yang, Z., Li, Q., 2013. Reduction of organic matter and trihalomethane formation potential in reclaimed water from treated municipal wastewater by coagulation and adsorption. Chemical engineering journal 223, 696-703.

Zhang, X., Li, J., Yu, Y., Xu, R., Wu, Z., 2016. Biofilm characteristics in natural ventilation trickling filters (NVTFs) for municipal wastewater treatment: Comparison of three kinds of biofilm carriers. Biochemical Engineering Journal 106, 87-96.

Zheng, X., Plume, S., Ernst, M., Croué, J.-P., Jekel, M., 2012. In-line coagulation prior to UF of treated domestic wastewater–foulants removal, fouling control and phosphorus removal. Journal of membrane science 403, 129-139.

Zheng, Y., Ye, Z.-L., Fang, X.-L., Li, Y.-H., Cai, W.-M., 2008. Production and characteristics of a bioflocculant produced by Bacillus sp. F19. Bioresource Technology 99(16), 7686-7691.

Zhou, Y., Xing, X.-H., Liu, Z., Cui, L., Yu, A., Feng, Q., Yang, H., 2008. Enhanced coagulation of ferric chloride aided by tannic acid for phosphorus removal from wastewater. Chemosphere 72(2), 290-298.

Zhu, G., Peng, Y., Li, B., Guo, J., Yang, Q., Wang, S., 2008. Biological removal of nitrogen from wastewater, Reviews of environmental contamination and toxicology. Springer, pp. 159-195.