TREATMENT OF PALM OIL MILL EFFLUENT BY ELECTROCOAGULATION PROCESS

MOHD NASRULLAH BIN ZULKIFLI

Doctor of Philosophy

UNIVERSITI MALAYSIA PAHANG

SUPERVISOR'S DECLARATION

We hereby declare that we have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Doctor of Philosophy.

____

(Supervisor's Signature)

Full Name : PROFESSOR DATO' DR. ZULARISAM BIN AB. WAHID

Position : DEAN FACULTY OF ENGINEERING TECHNOLOGY, UMP

Date :

____

(1^{st} Co-supervisor's Signature)

Full Name : PROFESSOR DR. MIMI SAKINAH BINTI ABDUL MUNAIM

Position : DEPUTY DEAN OF IPS, UMP

Date :

____

(2^{nd} Co-supervisor's Signature)

Full Name : DR. LAKHVEER SINGH

Position : SENIOR LECTURER, FTEK, UMP

Date :

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

____

(Student's Signature)

Full Name : MOHD NASRULLAH BIN ZULKIFLI

ID Number : PKE 13001

Date : 22 JUNE 2017

TREATMENT OF PALM OIL MILL EFFLUENT BY ELECTROCOAGULATION PROCESS

MOHD NASRULLAH BIN ZULKIFLI

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Doctor of Philosophy

Faculty of Engineering Technology
UNIVERSITI MALAYSIA PAHANG

JUNE 2017

ACKNOWLEDGEMENTS

My greatest wishes and thank to Allah, The Great Almighty God who gave my phD thesis appropriateness.

I am grateful and would like to express my sincere gratitude to my supervisor, Professor Dato' Dr. Zularisam bin Ab. Wahid for his germinal ideas, invaluable guidance, continuous encouragement and constant support in making this research possible. He has always impressed me with his outstanding professional conduct, his strong conviction for engineering, technology and science. I appreciate his consistent support from the first day I applied to graduate program till these concluding moments. I am truly grateful for his progressive vision during my training, his tolerance of my naïve mistake, and his commitment to my future career. I also sincerely thanks for the time spent proofreading and correcting my many mistakes. I am very lucky to have him as my supervisor and I believe that he is the best supervisor in the world, indeed.

It gives me great pleasure to acknowledge to the guidance, valuable suggestions, constructive criticism, and incredible patience of my co-supervisor: Profesor Datin Dr. Mimi Sakinah binti Abdul Munaim and Dr. Lakhveer Singh. Your scientific excitement inspired me in the most important moments of making right decisions and had significantly contributed to this thesis. Thank you for trusting me.

I acknowledge my sincere indebtedness and gratitude to my parents (Zulkifli Haron & Zainiah Hussin) and sisters for their incessantly prayers, love, dream and sacrifice throughout my life. I am also grateful to my wife (CS. Asmah), son (Muhammad Atiqullah) and daughters (Nur Al-Insyirah & Nur Irdhina) for their sacrifice, patience and understanding that were inevitable to make this work possible. I cannot find the appropriate words that could properly describe my appreciation for their devotion, support and faith in my ability to attain my goals.

Special thanks should be given to my friends, lab mates, postgrad roommates and staff members of Faculty of Engineering Technology, UMP, who help me in many ways and made me stay at UMP pleasant and unforgettable. I also would like to acknowledge their comments and suggestions, which was crucial for the successful completion of this study.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

A_a	active anode surface (mm^2)
A_p	projected area
D	global desirability function
d_1	average flocs size at steady state before breakage
d_2	flocs size at breakage
d_3	average flocs size at steady state after breakage
d_e	inter-electrode distance (mm)
d_{hor}	dimension in horizontal
d_i	desirability function
d_s	surface diameter
d_v	volumetric diameter
d_{ver}	dimension in vertical
e_r	residual error
F	Faraday's constant (96,485 C/mol)
f	response function
F_r	recovery factor
F_s	strength factor
I	the current (A)
k	specific conductivity
m	the mass of anode dissolution (g)
M_w	the molecular weight (g/mol)
P	perimeter
R	resistance (Ω)
R^2	coefficient of determination
R_{G1}	growth rate before breakage
R_{G2}	growth rate after breakage
S	floc surface area
t	the time of operation (s)
V	voltage (V)
X_1	current intensity factor for RSM
X_2	electrolysis time factor for RSM
X_3	inter-electrodes distance factor for RSM
X_4	pH factor for RSM
Y	response
Y_1	COD response for RSM
Y_2	BOD response for RSM
Y_3	SS response for RSM
z	the number of electrons involved in the reaction
η_{IR}	IR drop

LIST OF ABBREVIATIONS

ABF	Anaerobic Baffled Filter
ADF	Anaerobic Down-flow Filter
ADS	Anaerobically Digested Sludge
AHR	Anaerobic Hybrid Reactor
ANOVA	Analysis of Variance
A-PAM	Anionic Polyacrylamide
BBD	Box-Behnken Design
BC	Before Centuries
BOD	Biochemical Oxygen Demand
BP	Bipolar
C.V	Coefficient of Variation
COD	Chemical Oxygen Demand
C-PAM	Cationic Polyacrylamide
CPKO	Crude Palm Kernel Oil
CPO	Crude Palm Oil
DC	Direct Current
DO	Dissolved Oxygen
DOE	Department of Environment
DoE	Design Of Experiment
EDX	Energy Dispersive X-ray
EFB	Empty Fruit Bunches
EQA	Environment Quality Act
FESEM	Field Emission Scanning Electron Microscope
FFB	Fresh Fruit Bunch
FTIR	Fourier Transform Infrared Spectroscopy
HCPB	Hollow Centered Packed Bed
HR	High range
HRT	Hydraulic Retention Times
IAAB	Integrated Aerobic Anaerobic Bioreactor
MF	Fruit Fibers
MLSS	Mixed Liquor Suspended Solid
MLVSS	Mixed Liquor Volatile Suspended Solid
MP-P	Monopolar Parallel
MP-S	Monopolar Series
OFAT	One Factor at One Time
OLR	Organic Loading Rate
PACl	Polyaluminium Chloride
PKS	Palm Kernel Shells
POME	Palm Oil Mill Effluent
PRESS	Prediction Error Sum of Squares
RF	Rumen Fluid
RO	Reverse Osmosis
RSM	Response Surface Methodology
SBR	Sequencing Batch Reactor
SCSTR	Semi-continuous Stirred Tank Reactors
SI	International System
SS	Suspended Solid
SVI	Sludge Volume Index
TDS	Total Dissolve Solid
TOC	Total Organic Carbon
TP	Total Phosphorus
TSS	Total Suspended Solid

UASB	Up-flow Anaerobic Sludge Bed
UF	Ultra Filtration
UHR	Ultra High range
VFA	Volatile Fatty Acid
VFA/TA	Volatile Fatty Acid to Total Alkalinity
VSS	Volatile Suspended Solid
XRD	X-ray Powder Diffraction

TREATMENT OF PALM OIL MILL EFFLUENT BY ELECTROCOAGULATION PROCESS

MOHD NASRULLAH BIN ZULKIFLI

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Doctor of Philosophy

Faculty of Engineering Technology
UNIVERSITI MALAYSIA PAHANG

JUNE 2017

ABSTRAK

Sisa kumbahan kilang minyak kelapa sawit (POME) dikenali sebagai salah satu penyumbang terbesar kepada pencemaran air di Malaysia disebabkan oleh kepekatan permintaan oksigen kimia (COD), permintaan oksigen biokimia (BOD) dan pepejal terampai (SS) yang tinggi. Kaedah-kaedah seperti dengan menggunakan bahan kimia penggumpal, penjerapan, penapisan, rawatan aerobik dan anaerobik, sistem kolam dan sebagainya, memerlukan masa yang panjang dan bahan kimia yang substantif. Maka, rawatan menggunakan teknik elektropenggumpalan telah diperkenalkan dan digunakan. Proses ini menawarkan beberapa kelebihan yang tersendiri seperti kemudahan, keberkesanan, penjimatan masa dan memerlukan kawasan yang kecil sahaja. Sel elektrokimia telah berjaya direkabentuk untuk merawat POME dengan memilih orientasi menegak berbanding orientasi mendatar kerana ianya telah memperolehi penyingkiran COD, BOD dan SS yang tertinggi iaitu masing-masing adalah 57, 53 dan 51%. Monopolar bersiri (MP-S) telah dipilih sebagai susunan elektrod berbanding monopolar selari (MP-P) dan bipolar (BP) kerana memiliki penyikiran tertinggi iaitu 65, 62 dan 60% untuk COD, BOD dan SS masing-masing. Sabut besi dipilih sebagai bahan dan jenis struktur untuk elektrod berbanding plat besi dan aluminium kerana penyingkiran tertingginya masing-masing pada 74, 70 dan 66% untuk COD, BOD dan SS. Parameter beroperasi seperti tempoh masa elektrolisis, keamatan arus, jarak antara elektrod dan pH awal mempunyai pengaruh yang besar terhadap penyingkiran COD, BOD dan SS. Julat terbaik bagi parameter operasi untuk merawat POME dengan berkesan didapati 30 hingga 50 minit untuk tempoh masa elektrolisis, 15 hingga 20 A untuk keamatan arus, 5 hingga 15 mm untuk jarak antara elektrod dan 3 hingga 6 untuk nilai pH awal. Penggunaan elektrik sering menjadi faktor pengehad di dalam proses electrocoagulation, maka keamatan arus yang tinggi (15, 20 dan 25 A) telah diperkenalkan dan dikaji untuk meningkatkan keberkesanan proses. Untuk analisis saiz zarah, purata saiz gumpalan pada keadaan stabil pertama, keadaan pemecahan, keadaan stabil kedua, faktor kekuatan, faktor pemulihan, kadar pertumbuhan pertama dan kadar pemulihan kedua adalah 336 μm, 223 μm, 333 μm, 66.37%, 97.35%, 20.94 μm/min dan 11.89 μm/min. Purata saiz gumpalan pada keadaan stabil kedua bagi keamatan arus untuk 1, 5, 10, 15, 20 dan 25 A masing-masing adalah 168, 252, 333, 463, 538 and 550 μm. Purata saiz gumpalan pada keadaan stabil kedua bagi jarak antara elektrod-elektrod untuk 5, 10, 15, 20, 25 dan 30 mm masing-masing adalah 214, 228, 208, 168, 138 and 97 μm. Purata saiz gumpalan pada keadaan stabil kedua bagi pH untuk 2, 3, 4, 5, 6, 7, 8 dan 9 masing-masing adalah 216, 244, 275, 267, 236, 191, 175 dan 163 μm. Kajian RSM menunjukkan penyingkiran optimum dicapai pada 19.07 A, 44.97 minit, jarak 8.60 mm dan pH 4.37. Hasil jangkaan di bawah keadaan optimum tersebut masing-masing adalah 97.21, 99.26 dan 99.00% untuk penyingkiran COD, BOD dan SS. Kajian pengesahan masing-masing menunjukkan 95.03, 94.52 dan 96.12% untuk penyingkiran COD, BOD dan SS dengan ralat masing-masing sebanyak 2.29, 5.01 dan 1.96%. Secara keseluruhannya, rawatan menggunakan proses elektropenggumpalan menunjukkan keberkesanan dan juga menjimatkan masa dalam meyingkirkan bahan pencemar daripada POME.

ABSTRACT

Palm oil mill effluent (POME) is known to be one of the major attributer to water pollution in Malaysia due to its high concentration of chemical oxygen demand (COD), biochemical oxygen demand (BOD) and suspended solid (SS). Various techniques of effluent treatment such as chemical coagulation, adsorption, filtration, aerobic and anaerobic treatment, ponding system etc., have disadvantages such as high retention time and substantive chemical substances. Therefore, in this study electrocoagulation technique was introduced and applied. This process offers some distinctive advantages including a simple set-up, effectively remove high concentration of pollutant, short treatment time and requires only a small treatment space. Electrochemical cell has been successfully designed for POME treatment by choosing the vertical over horizontal orientation which subsequently resulted the highest removal of 57, 53 and 5% for COD, BOD and SS respectively. Monopolar series (MP-S) has been chosen instead of monopolar parallel (MP-P) and bipolar (BP) as the electrode arrangement due to the highest removal of 65, 62 and 60% for COD, BOD and SS respectively. Steel wool has been chosen rather than iron and aluminium plate for the highest removal of 74, 70 and 66% of COD, BOD and SS respectively. Operating parameters such as electrolysis time, current intensity, inter-electrode distance and initial pH have a great influence on the removal of COD, BOD and SS. The best effective range of operating parameters to treat POME were found to be 30 to 50 minutes for electrolysis time, 15 to 20 A for current intensity, 5 to 15 mm for inter-electrode distances and 3 to 6 for initial pH value. Electricity consumption is often become the limiting factor in the electrocoagulation process, therefore in this research, the high intensity of the current (15, 20 and 25) has been introduced and studied to improve the effectiveness of the process. For particle size analysis, the average flocs size at first steady-state, floc size at breakage state, average size at second steady-state, strength factor, recovery factor, first growth rate and second growth rate were found to be 336 μm, 223 μm, 333 μm, 66.37%, 97.35%, 20.94 μm/min and 11.89 μm/min. The average flocs size at the second steady-state for 1, 5 10, 15 20 and 25 A of current intensity were 168, 252, 333, 463, 538 and 550 μm respectively. The average flocs size at the second steady-state for 5, 10, 15, 20, 25 and 30 mm of inter-electrode distances were 214, 228, 208, 168, 138 and 97 μm respectively. The average flocs size at second-steady state for pH 2, 3, 4, 5, 6, 7, 8 and 9 were found to be 216, 244, 275, 267, 236, 191, 175 and 163 μm respectively. The optimization study using response surface methodology (RSM) indicated that the optimal COD, BOD and SS removals were achieved at 19.07 A of current intensity, 44.97 minutes of treatment time, 8.60 mm of electrode distance and 4.37 of pH. The predicted results under this optimized condition were 97.21, 99.26 and 99.00% for COD, BOD and SS removal respectively. The validation experiment showed 95.03, 94.52 and 96.12% for COD, BOD and SS removal with 2.29%, 5.01% and 1.96% of standard error respectively. Overall, the treatment by using electrocoagulation process demonstrated an effectiveness and time saving technique for pollutant removal from POME.

REFERENCES

Abdullah, N., Ujang, Z., & Yahya, A. (2011). Aerobic granular sludge formation for high strength agro-based wastewater treatment. *Bioresource Technology, 102,* 6778–6781.

Abuzaid, N.S., Bukhari, A.A., & Al-Hamouz, Z.M. (2002). Ground water coagulation using soluble stainless steel electrodes. *Advances in Environmental Research, 6,* 325–333.

Adachi, Y. (2016). Sedimentation and electrophoresis of a porous floc and a colloidal particle coated with polyelectrolytes. *Current Opinion in Colloid and Interface Science, 24,* 72–78.

Aguilar, M.I., Sáez, J., Lloréns, M., Soler, A., & Ortuño, J.F. (2003). Microscopic observation of particle reduction in slaughterhouse wastewater by coagulation-flocculation using ferric sulphate as coagulant and different coagulant aids. *Water Research, 37,* 2233–2241.

Agustin, M.B., Sengpracha, W.P., & Phutdhawong, W. (2008). Electrocoagulation of palm oil mill effluent. *International Journal of Environmental Research and Public Health, 5,* 177–180.

Ahmad, A.L., Ibrahim, N., Ismail, S., & Bhatia, S. (2002). Coagulation-Sedimentation-Extraction Pretreatment Methods for the Removal of Suspended Solids and Residual Oil From Palm Oil Mill Effluent (Pome). *IIUM Engineering Journal, 3,* 25–33.

Ahmad, A.L., Ismail, S., & Bhatia, S. (2003). Water recycling from palm oil mill effluent (POME) using membrane technology. *Desalination, 157,* 87–95.

Ahmad, A.L., Wong, S.S., Teng, T.T., & Zuhairi, A. (2008). Improvement of alum and PACl coagulation by polyacrylamides (PAMs) for the treatment of pulp and paper mill wastewater. *Chemical Engineering Journal, 137,* 510–517.

Akyol, A. (2012). Treatment of paint manufacturing wastewater by electrocoagulation. *Desalination, 285,* 91–99.

Alrawi, R.A., Ahmad, A., Ismail, N., & Kadir, M.O.A. (2011). Anaerobic co-digestion of palm oil mill effluent with rumen fluid as a co-substrate. *Desalination, 269,* 50–57.

Amuda, O.S., & Alade, A. (2006). Coagulation/flocculation process in the treatment of abattoir wastewater. *Desalination, 196,* 22–31.

Amuda, O.S., & Amoo, I.A. (2007). Coagulation/flocculation process and sludge conditioning in beverage industrial wastewater treatment. *Journal of Hazardous Materials, 141,* 778–783.

Aouni, A., Fersi, C., Ben Sik Ali, M., & Dhahbi, M. (2009). Treatment of textile wastewater by a hybrid electrocoagulation/nanofiltration process. *Journal of Hazardous Materials, 168,* 868–874.

Aqilah, N., Fadzil, M., Zainal, Z., & Abdullah, A.H. (2013). COD Removal for Palm Oil Mill Secondary Effluent by Using UV/ Ferrioxalate/ TiO_2/ O_3 system. *International Journal of Emerging Technology and Advanced Engineering, 3,* 237-243.

Arnold, A. (2008). *Evaluation and Quantification of Engineered Flocs and Drinking Water.* (Ph.D. Thesis). University of Waterloo, Canada.

Asano, T., & Cotruvo, J.A. (2004). Groundwater recharge with reclaimed municipal wastewater: Health and regulatory considerations. *Water Research, 38*, 1941–1951.

Aswathy, P., Gandhimathi, R., Ramesh, S.T., & Nidheesh, P.V. (2016). Removal of organics from bilge water by batch electrocoagulation process. *Separation and Purification Technology, 159,* 108–115.

Azmi, A., Siew, O.B., Kee, S., & Ujang, Z. (2008). Tertiary treatment of palm oil mill effluent using fenton oxidation. *Malaysian Journal Of Civil Engineering, 20,* 12–25.

Basiron, Y. (2007). Palm oil production through sustainable plantations. *European Journal of Lipid Science and Technology, 109,* 289–295.

Basiron, Y., & Weng, C.K. (2004). The oil palm and its sustainability. *Journal of Oil Palm Research, 16,* 1–10.

Bayar, S., Yildiz, Y.S., Yilmaz, A.E., & Irdemez, S. (2011). The effect of stirring speed and current density on removal efficiency of poultry slaughterhouse wastewater by electrocoagulation method. *Desalination, 280,* 103–107.

Bharti, I., & Ray, A. (2015). Study of mechanical and water barrier properties of chitosan based edible films affected by process parameters by using response surface methodology. *International Journal of Research Studies in Biosciences, 3,* 91–97.

Bhatia, S., Othman, Z., & Ahmad, A.L. (2007). Coagulation-flocculation process for POME treatment using Moringa oleifera seeds extract: Optimization studies. *Chemical Engineering Journal, 133,* 205–212.

Bouyer, D., Coufort, C., Liné, A., & Do-Quang, Z. (2005). Experimental analysis of floc size distributions in a 1-L jar under different hydrodynamics and physicochemical conditions. *Journal of Colloid and Interface Science, 292,* 413–428.

Bratby, J. (2006). *Coagulation and flocculation in water and wastewater treatment.* London: IWA Publishing.

Bukhari, A.A. (2008). Investigation of the electro-coagulation treatment process for the removal of total suspended solids and turbidity from municipal wastewater. *Bioresource Technology, 99,* 914–921.

Cao, Z. (2009). *Determination of Particle Size Distribution of Particulate Matter Emitted from a Layer Operation in Southeast U.S.* Ph.D. Thesis. North Carolina State University, USA.

Chafi, M., Gourich, B., Essadki, A.H., Vial, C., & Fabregat, A. (2011). Comparison of electrocoagulation using iron and aluminium electrodes with chemical coagulation for the removal of a highly soluble acid dye. *Desalination, 281,* 285–292.

Chakraborti, R.K., Atkinson, J.F., & Van Benschoten, J.E. (2000). Characterization of alum floc by image analysis. *Environmental Science and Technology, 34,* 3969–3976.

Chan, Y.J., Chong, M.F., & Law, C.L. (2011). Optimization on thermophilic aerobic treatment of anaerobically digested palm oil mill effluent (POME). *Biochemical Engineering Journal, 55,* 193–198.

Chan, Y.J., Chong, M.F., & Law, C.L. (2012). An integrated anaerobic-aerobic bioreactor (IAAB) for the treatment of palm oil mill effluent (POME): Start-up and steady state performance. *Process Biochemistry, 47,* 485–495.

Chang, S.W., & Shaw, J.F. (2009). Biocatalysis for the production of carbohydrate esters. *New Biotechnology, 26,* 109–116.

Chaudhari, P.K., Mishra, I.M., & Chand, S. (2007). Decolourization and removal of chemical oxygen demand (COD) with energy recovery: Treatment of biodigester effluent of a molasses-based alcohol distillery using inorganic coagulants. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *296,* 238–247.

Chen, G. (2004). Electrochemical technologies in wastewater treatment. *Separation and Purification Technology, 38,* 11–41.

Chen, X., Chen, G., & Yue, P.L. (2000). Separation of pollutants from restaurant wastewater by electrocoagulation. *Separation and Purification Technology, 19,* 65–76.

Choi, W.H., Shin, C.H., Son, S.M., Ghorpade, P.A., Kim, J.J., & Park, J.Y. (2013). Anaerobic treatment of palm oil mill effluent using combined high-rate anaerobic reactors. *Bioresource Technology, 141,* 138–44.

Daneshvar, N., Ashassi-Sorkhabi, H., & Tizpar, A. (2003). Decolorization of orange II by electrocoagulation method. *Separation and Purification Technology, 31,* 153–162.

Daneshvar, N., Khataee, A.R., & Djafarzadeh, N. (2006). The use of artificial neural networks (ANN) for modeling of decolorization of textile dye solution containing C. I. Basic Yellow 28 by electrocoagulation process. *Journal of Hazardous Materials, 137*, 1788–95.

Daneshvar, N., Oladegaragoze, A., & Djafarzadeh, N. (2006). Decolorization of basic dye solutions by electrocoagulation: An investigation of the effect of operational parameters. *Journal of Hazardous Materials, 129,* 116–22.

Daneshvar, N., Sorkhabi, H.A., & Kasiri, M.B. (2004). Decolorization of dye solution containing Acid Red 14 by electrocoagulation with a comparative investigation of different electrode connections. *Journal of Hazardous Materials, 112,* 55–62.

Demirci, Y., Pekel, L.C., & Alpbaz, M. (2015). Investigation of different electrode connections in electrocoagulation of textile wastewater treatment. *International Journal of Electrochemical Science, 10,* 2685–2693.

Demircio, N. (2006). The effects of current density and phosphate concentration on phosphate removal from wastewater by electrocoagulation using aluminum and iron plate electrodes. *Separation and Purification Technology, 52,* 218–223.

Dennett, K.E., Amirtharajah, A., Moran, T.F., & Gould, J.P.(1996). Coagulation: Its effect on organic matter. *Journal - American Water Works Association*, *88,* 129–142.

Drogui, P., Brar, S.K., & Benmoussa, H. (2008). Electrochemical removal of pollutants from agro-industry wastewaters. *Separation and Purification Technology, 61,* 301–310.

Duan, J., & Gregory, J. (2003). Coagulation by hydrolysing metal salts. *Advances in Colloid and Interface Science, 100,* 475–502.

Eisma, D. (1986). Flocculation and de-flocculation of suspended matter in estuaries. *Netherlands Journal of Sea Research, 20,* 183–199.

Elnenay, A.M.H., Nassef, E., Malash, G.F., & Magid, M.H.A. (2016). Treatment of drilling fluids wastewater by electrocoagulation. *Egyptian Journal of Petroleum, 26,* 4–9.

Environmental Quality Act 1974. (2004). *Federal Subsidiary Legislation Environmental Quality Act 1974 (Revised 2004).* (Act 127).

Essadki, A.H., Bennajah, M., Gourich, B., Vial, C., Azzi, M., & Delmas, H. (2008). Electrocoagulation/electroflotation in an external-loop airlift reactor-Application to the decolorization of textile dye wastewater: A case study. *Chemical Engineering and Processing: Process Intensification, 47,* 1211–1223.

Fadali, O.A., Ebrahiem, E.E., El-Gamil, A., & Altaher, H. (2016). Investigation of the electrocoagulation treatment technique for the separation of oil from wastewater. *Journal of Environmental Science and Technology, 9*, 62–74.

Fouad, Y.O.A., Konsowa, A.H., Farag, H.A., & Sedahmed, G.H. (2009). Performance of an electrocoagulation cell with horizontally oriented electrodes in oil separation compared to a cell with vertical electrodes. *Chemical Engineering Journal, 145,* 436–440.

Fuad. M (2008). *Low Electric Energy for Colour Removal of Dye Solution.* (Ph.D. Thesis). Universiti Teknologi Malaysia, Malaysia.

Gao, B.Y., Wang, Y., Yue, Q.Y., Wei, J.C., & Li, Q. (2008). The size and coagulation behavior of a novel composite inorganic-organic coagulant. *Separation and Purification Technology, 62,* 544–550.

Garg, K.K., & Prasad, B. (2016). Development of Box Behnken design for treatment of terephthalic acid wastewater by electrocoagulation process: Optimization of process and analysis of sludge. *Journal of Environmental Chemical Engineering, 4,* 178–190.

Gengec, E., Kobya, M., Demirbas, E., Akyol, A., & Oktor, K. (2012). Optimization of baker's yeast wastewater using response surface methodology by electrocoagulation. *Desalination, 286*, 200–209.

Gregory, J., & Duan, J. (2001). Hydrolyzing metal salts as coagulants. *Pure and Applied Chemistry, 73,* 2017–2026.

Gui, J.L. (2009). Effect of pH and chloride concentration on the removal of hexavalent chromium in a batch electrocoagulation reactor. *Journal of Hazardous Materials, 169,* 1127–1133.

Gurmu, G.T. (2013). *Impact of Coagulant Type and Ion Exchange (IEX) Pretreatment on Floc Strength and Structure at The Kluizen WTP*. Ph.D Thesis. Universitiet Gent, Belgium.

Gürses, A., Yalçin, M., & Doğar, C. (2002). Electrocoagulation of some reactive dyes: A statistical investigation of some electrochemical variables. *Waste Management, 22,* 491–499.

Gursoy-Haksevenler, B.H., & Arslan-Alaton, I. (2015). Evidence of inert fractions in olive mill wastewater by size and structural fractionation before and after thermal acid cracking treatment. *Separation and Purification Technology, 154, 1*76–185.

Guzmán, J., Mosteo, R., Sarasa, J., Alba, J.A., & Ovelleiro, J.L. (2016). Evaluation of solar photo-Fenton and ozone based processes as citrus wastewater pre-treatments. *Separation and Purification Technology, 164,* 155–162.

Hakizimana, J.N., Gourich, B., Chafi, M., Stiriba, Y., Vial, C., Drogui, P., & Naja, J. (2017). Electrocoagulation process in water treatment: A review of electrocoagulation modeling approaches. *Desalination, 404*, 1–21.

Hanafi, F., Assobhei, O., & Mountadar, M. (2010). Detoxification and discoloration of Moroccan olive mill wastewater by electrocoagulation. *Journal of Hazardous Materials, 174,* 807–12.

Holt, P., Barton, G., & Mitchell, C. (2006). Electrocoagulation as a Wastewater Treatment. *The Third Annual Australian Environmental Engineering Research Event.* pp. 23-26.

Holt, P.K., Barton, G.W., & Mitchell, C.A. (2005). The future for electrocoagulation as a localised water treatment technology. *Chemosphere, 59,* 355–367.

Huang, X., Sun, S., Gao, B., Yue, Q., Wang, Y., & Li, Q. (2015). Coagulation behavior and floc properties of compound bioflocculant-polyaluminum chloride dual-coagulants and polymeric aluminum in low temperature surface water treatment. *Journal of Environmental Sciences (China), 30,* 215–222.

Ibrahim, D.S. (2013). *Treatment of Petroleum Refinery Effluent Using Electrochemical Techniques.* (Ph.D Thesis). Anna University, India.

Igwe, J.C., & Onyegbado, C.C. (2007). A review of palm oil mill effluent (POME) water treatment. *Global Journal of Environmental Research, 1,* 54–62.

Ilhan, F., Kurt, U., Apaydin, O., & Gonullu, M.T. (2008). Treatment of leachate by electrocoagulation using aluminum and iron electrodes. *Journal of Hazardous Materials, 154,* 381–389.

Irdemez, Ş., Demircioğlu, N., & Yildiz, Y.Ş. (2006). The effects of pH on phosphate removal from wastewater by electrocoagulation with iron plate electrodes. *Journal of Hazardous Materials, 137,* 1231–1235.

Jarvis, P., Jefferson, B., & Parsons, S.A. (2005). Measuring floc structural characteristics. *Reviews in Environmental Science and Bio/Technology, 4,* 1–18.

Jiang, D., & Li, B. (2009). Granular activated carbon single-chamber microbial fuel cells (GAC-SCMFCs): A design suitable for large-scale wastewater treatment processes. *Biochemical Engineering Journal, 47,* 31–37.

Jing-Wei, F., Ya-Bing, S.U.N., Zheng, Z., Ji-Biao, Z., Shu, L.I., & Yuan-Chun, T. (2007). Treatment of tannery wastewater by electrocoagulation. *Journal of Environmental Sciences, 19,* 1409–1415.

Karhu, M., Kuokkanen, V., Kuokkanen, T., & Rämö, J. (2012). Bench scale electrocoagulation studies of bio oil-in-water and synthetic oil-in-water emulsions. *Separation and Purification Technology, 96,* 296–305.

Katal, R., & Pahlavanzadeh, H. (2011). Influence of different combinations of aluminum and iron electrode on electrocoagulation efficiency: Application to the treatment of paper mill wastewater. *Desalination, 265,* 199–205.

Khalaf, A.M., Mubarak, A.A., & Nosier, S.A. (2016). Removal of Cr(VI) by electrocoagulation using vertical and horizontal rough cylinder anodes. *International Journal of Electrochemical Science, 11,* 1601–1610.

Khandegar, V., & Saroha, A.K. (2013). Electrocoagulation for the treatment of textile industry effluent - A review. *Journal of Environmental Management, 128,* 949–963.

Khemkhao, M., Nuntakumjorn, B., Techkarnjanaruk, S., & Phalakornkule, C. (2012). UASB performance and microbial adaptation during a transition from mesophilic to thermophilic treatment of palm oil mill effluent. *Journal of Environmental Management, 103,* 74–82.

Kiliç, M.G. (2009). *A parametric comparative study of electrocoagulation and coagulation of aqueous suspensions of kaolinite and quartz powders.* (Ph.D Thesis). Middle East Technical University, Turkey.

Kiliç, M.G., & Hoşten, Ç. (2010). A comparative study of electrocoagulation and coagulation of aqueous suspensions of kaolinite powders. *Journal of Hazardous Materials, 176,* 735–740.

Kim, S.C. (2016). Application of response surface method as an experimental design to optimize coagulation–flocculation process for pre-treating paper wastewater. *Journal of Industrial and Engineering Chemistry, 38,* 93–102.

Kim, T., Park, C., Shin, E., & Kim, S. (2002). Decolorization of disperse and reactive dyes by continuous electrocoagulation process. *Desalination, 150,* 165–175.

Kobya, M., Can, O.T., & Bayramoglu, M. (2003). Treatment of textile wastewaters by electrocoagulation using iron and aluminum electrodes. *Journal of Hazardous Materials, 100,* 163–178.

Kobya, M., & Demirbas, E. (2015). Evaluations of operating parameters on treatment of can manufacturing wastewater by electrocoagulation. *Journal of Water Process Engineering, 8,* 64–74.

Kobya, M., Gebologlu, U., Ulu, F., Oncel, S., & Demirbas, E. (2011). Removal of arsenic from drinking water by the electrocoagulation using Fe and Al electrodes. *Electrochimica Acta, 56,* 5060–5070.

Kobya, M., Gengec, E., & Demirbas, E. (2016). Operating parameters and costs assessments of a real dyehouse wastewater effluent treated by a continuous electrocoagulation process. *Chemical Engineering and Processing: Process Intensification, 101,* 87–100.

Kobya, M., Hiz, H., Senturk, E., Aydiner, C., & Demirbas, E. (2006). Treatment of potato chips manufacturing wastewater by electrocoagulation. *Desalination, 190,* 201–211.

Koocheki, A., Taherian, A.R., Razavi, S.M.A., & Bostan, A. (2009). Response surface methodology for optimization of extraction yield, viscosity, hue and emulsion stability of mucilage extracted from Lepidium perfoliatum seeds. *Food Hydrocolloids, 23,* 2369–2379.

Kumar, M., Ponselvan, F.I.A., Malviya, J.R., Srivastava, V.C., & Mall, I.D. (2009). Treatment of bio-digester effluent by electrocoagulation using iron electrodes. *Journal of Hazardous Materials, 165,* 345–352.

Lam, M.K., & Lee, K.T. (2011). Renewable and sustainable bioenergies production from palm oil mill ef fl uent (POME): Win – win strategies toward better environmental protection. *Biotechnology Advances, 29,* 124–141.

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

Li, T., Zhu, Z., Wang, D., Yao, C., & Tang, H. (2006). Characterization of floc size, strength and structure under various coagulation mechanisms. *Powder Technology, 168,* 104–110.

Li, X., Song, J., Guo, J., Wang, Z., & Feng, Q. (2011). Landfill leachate treatment using electrocoagulation. *Procedia Environmental Sciences, 10,* 1159–1164.

Liew, W.L., Kassim, M.A., Muda, K., Loh, S.K., & Affam, A.C. (2014). Conventional methods and emerging wastewater polishing technologies for palm oil mill effluent treatment: A review. *Journal of Environmental Management, 149,* 222–235.

Lim, J.X., & Vadivelu, V.M. (2014). Treatment of agro based industrial wastewater in sequencing batch reactor: Performance evaluation and growth kinetics of aerobic biomass. *Journal of Environmental Management, 146,* 217–225.

Lorestani, A.A.Z. (2006). *Biological treatment of palm oil mill effluent (POME) using an up-flow anaerobic sludge fixed film (UASFF) bioreactor.* (Ph.D Thesis). Universiti Sains Malaysia, Malaysia.

Ma, J., Wang, Y., Zhang, X., & Huang, H. (2016). Filtration of protein colloids by fibrous membranes: A mechanistic investigation using packed bed filtration approach. *Colloids and Surfaces A: Physicochemical and Engineering Aspects, 502,* 44–53.

Madaki, Y.S., & Seng, L. (2013). Palm oil mill effluent (POME) from Malaysia palm oil mills : waste or resource. *International Journal of Environmental Science and Technology, 2,* 1138–1155.

Mahmoud, M.S., Farah, J.Y., & Farrag, T.E. (2013). Enhanced removal of Methylene Blue by electrocoagulation using iron electrodes. *Egyptian Journal of Petroleum, 22*, 211–216.

Mailler, R., Gasperi, J., Coquet, Y., Derome, C., Bulet, A., Vulliet, E., Bressy, A., Varrault, G., Chebbo, G., & Rocher, V. (2016). Removal of emerging micropollutants from wastewater by activated carbon adsorption: Experimental study of different activated carbons and factors influencing the adsorption of micropollutants in wastewater. *Journal of Environmental Chemical Engineering, 4,* 1102–1109.

Majlesi, M., Mohseny, S.M., Sardar, M., Golmohammadi, S., & Sheikhmohammadi, A. (2016). Improvement of aqueous nitrate removal by using continuous electrocoagulation/electroflotation unit with vertical monopolar electrodes. *Sustainable Environment Research, 26,* 287–290.

Makki, H.F., Al-Alawy, A.F., Abdul-Razaq, N.N., & Mohammed, M.A. (2010). Using aluminum refuse as a coagulant in the coagulation and flocculation processes. *Iraqi Journal of Chemical and Petroleum Engineering, 11,* 15–22.

Mancell-Egala, W.A.S.K., Su, C., Takacs, I., Novak, J.T., Kinnear, D.J., Murthy, S.N., & De Clippeleir, H. (2017). Settling regimen transitions quantify solid separation limitations through correlation with floc size and shape. *Water Research, 109,* 54–68.

Manning, A.J., & Schoellhamer, D.H., (2013). Factors controlling floc settling velocity along a longitudinal estuarine transect. *Marine Geology, 345,* 266–280.

Merzouk, B., Gourich, B., Madani, K., Vial, C., & Sekki, A. (2011). Removal of a disperse red dye from synthetic wastewater by chemical coagulation and continuous electrocoagulation. A comparative study. *Desalination, 272*, 246–253.

Merzouk, B., Madani, K., & Sekki, A. (2010). Using electrocoagulation-electroflotation technology to treat synthetic solution and textile wastewater, two case studies. *Desalination, 250,* 573–577.

Mohammadizaroun, M., & Yusoff, M.S. (2014). Review paper treatment of leachate by electrocoagulation technique using iron and hybrid electrodes. *International Journal of Scientific Research in Knowledge, 2,* 497-508.

Mohammed, M., Aziz, A., & Raman, A. (2017). Trend and current practices of palm oil mill effluent polishing : Application of advanced oxidation processes and their future perspectives. *Journal of Environmental Management, 198,* 170–182.

Mohammed, R.R., Ketabachi, M.R., & McKay, G. (2014). Combined magnetic field and adsorption process for treatment of biologically treated palm oil mill effluent (POME). *Chemical Engineering Journal, 243,* 31–42.

Mollah, M.Y.A., Morkovsky, P., Gomes, J.A.G., Kesmez, M., Parga, J., & Cocke, D.L. (2004). Fundamentals, present and future perspectives of electrocoagulation. *Journal of Hazardous Materials, 114,* 199–210.

Mollah, M.Y.A., Pathak, S.R., Patil, P.K., Vayuvegula, M., Agrawal, T.S., Gomes, J.A.G., Kesmez, M., & Cocke, D.L. (2004). Treatment of orange II azo-dye by electrocoagulation (EC) technique in a continuous flow cell using sacrificial iron electrodes. *Journal of Hazardous Materials, 109,* 165–71.

Montgomery, D.C. (2012). *Design and analysis of experiments.* Arizona, USA: John Wiley & Sons, Inc.

Moreno, H.A.C., Cocke, D.L., Gomes, J.A.G., Morkovsky, P., Parga, J.R., Peterson, E., & Garcia, C. (2009). Electrochemical reactions for electrocoagulation using iron electrodes. *Industrial & Engineering Chemistry Research, 48,* 2275–2282.

Mouedhen, G., Feki, M., De Petris-Wery, M., & Ayedi, H.F. (2009). Electrochemical removal of Cr(VI) from aqueous media using iron and aluminum as electrode materials: Towards a better understanding of the involved phenomena. *Journal of Hazardous Materials,* 168, 983–991.

Moussa, D.T., El-Naas, M.H., Nasser, M., & Al-Marri, M.J. (2016). A comprehensive review of electrocoagulation for water treatment: Potentials and challenges. *Journal of Environmental Management, 186,* 24–41.

MPOB, (2015a). *A-Production of crude palm oil for the month of December 2015 January to June 2014 and 2015 (tonnes).* (online). Retrieved from http://bepi.mpob.gov.my/ index.php/statistics/production/135-production-2015/736-production-of-crude-oil-palm-2015.html on 30 November 2016.

MPOB, (2015b). *B-Monthly export of oil palm products in 2015.* (online). Retrieved from http://bepi.mpob.gov.my/index.php/statistics/export/138-export-2015/759-monthly-export-of-oil-palm-products-2015.html on 30 November 2016.

Muhamad, M.H., Sheikh Abdullah, S.R., Mohamad, A.B., Abdul Rahman, R., & Hasan Kadhum, A.A. (2013). Application of response surface methodology (RSM) for optimisation of COD, NH_3-N and 2,4-DCP removal from recycled paper wastewater in a pilot-scale granular activated carbon sequencing batch biofilm reactor (GAC-SBBR). *Journal of Environmental Management, 121,* 179–190.

Myers, R.H., & Montgomery, D.C. (2002). *Response Surface Methodology: Process and Product Optimization Using Designed Experiments.* USA: John Wiley & Sons, Inc.

Naje, A.S., & Abbas, S.A. (2013). Electrocoagulation technology in wastewater treatment : a review of methods and applications. *Civil and Environmental Research, 3,* 29–43.

Naje, A.S., Chelliapan, S., Zakaria, Z., & Abbas, S.A., (2015a). Treatment performance of textile wastewater using electrocoagulation (EC) process under combined electrical connection of electrodes. *International Journal of Electrochemical Science, 10,* 5924–5941.

Naje, A.S., Chelliapan, S., Zakaria, Z., & Abbas, S.A., (2015b). Enhancement of an electrocoagulation process for the treatment of textile wastewater under combined electrical connections using titanium plates. *International Journal of Electrochemical Science, 10,* 4495–4512.

Nasution, A., Ng, B.L., Ali, E., Yaakob, Z., & Kamarudin, S.K. (2014). Electrocoagulation of palm oil mill effluent for treatment and hydrogen production using response surface methodology. *Polish Journal of Environmental Studies, 23,* 1669–1677.

Nater, J., William, W., & Michael, H.K. (1990). *Applied Linear Statistical Models.* USA: CRC Press.

Norfadilah, N., Raheem, A., & Harun, R. (2016). Bio-hydrogen production from palm oil mill effluent (POME): A preliminary study. *International Journal of Hydrogen Energy, 41,* 3–7.

Otieno, N.E., Dai, X., Barba, D. De, Bahman, A., Smedbol, E., Rajeb, M., & Jaton, L. (2016). Palm oil production in malaysia : an analytical systems model for balancing economic prosperity , forest conservation and social welfare. *Agricultural Sciences, 7,* 55–69.

Ozyonar, F., & Karagozoglu, B. (2011). Operating cost analysis and treatment of domestic wastewater by electrocoagulation using aluminum electrodes. *Polish Journal of Environmental Studies, 20,* 173–179.

Phalakornkule, C., Polgumhang, S., & Tongdaung, W. (2009). Performance of an electrocoagulation process in treating direct dye: Batch and continuous upflow processes. *World Academy of Science, Engineering and Technology, 3,* 267–272.

Pishgar-Komleh, S.H., Keyhani, A., Mostofi-Sarkari, M., & Jafari, A. (2012). Optimization of seed corn harvesting losses applying response surface methodology. *Research Journal of Applied Sciences, Engineering and Technology, 4*, 2350–2356.

Poh, P.E., & Chong, M.F. (2009). Development of anaerobic digestion methods for palm oil mill effluent (POME) treatment. *Bioresource Technology, 100,* 1–9.

Poh, P.E., & Chong, M.F. (2014). Upflow anaerobic sludge blanket-hollow centered packed bed (UASB-HCPB) reactor for thermophilic palm oil mill effluent (POME) treatment. *Biomass and Bioenergy, 67,* 231–242.

Prajapati, A.K., Chaudhari, P.K., Pal, D., Chandrakar, A., & Choudhary, R. (2016). Electrocoagulation treatment of rice grain based distillery effluent using copper electrode. *Journal of Water Process Engineering, 11,* 1–7.

Ricordel, C., & Djelal, H. (2014). Treatment of landfill leachate with high proportion of refractory materials by electrocoagulation: System performances and sludge settling characteristics. *Journal of Environmental Chemical Engineering, 2,* 1551–1557.

Roda, J.M., Goralski, M., Benoist, A., Baptiste, A., Boudjema, V., Galanos, T., Georget, M., Hévin, J.-E., Lavergne, S., Eychenne, F., Liew, K.E., Schwob, C., Djama, M., & Tahir, P.M. (2016). *Sustainability of bio-jetfuel in Malaysia.* France: CIRAD.

Rupani, P., & Singh, R. (2010). Review of current palm oil mill effluent (POME) treatment methods: Vermicomposting as a sustainable practice. *World Applied Sciences Journal, 11,* 70–81.

Saeed, M.O., Azizli, K., Isa, M.H., & Bashir, M.J.K. (2015). Application of CCD in RSM to obtain optimize treatment of POME using fenton oxidation process. *Journal of Water Process Engineering, 8,* 7–16.

Sahu, O.P., & Chaudhari, P.K. (2013). Review on chemical treatment of industrial waste water review on chemical treatment. *Journal of Applied Sciences and Environmental Management, 17,* 241–257.

Sankar, S., & Dharmendra, (2016). Electrocoagulation for the treatment of water and waste water- Review. *International Journal of Modern Trends in Engineering and Research, 3,* 101–105.

Sengil, I.A., Kulaç, S., & Ozacar, M. (2009). Treatment of tannery liming drum wastewater by electrocoagulation. *Journal of Hazardous Materials, 167,* 940–6.

Sengil, I.A., & Ozacar, M. (2009). The decolorization of C.I. Reactive Black 5 in aqueous solution by electrocoagulation using sacrificial iron electrodes. *Journal of Hazardous Materials, 161,* 1369–76.

Şengil, I.A., & Özacar, M. (2006). Treatment of dairy wastewaters by electrocoagulation using mild steel electrodes. *Journal of Hazardous Materials, 137,* 1197–1205.

Shafaei, A., Pajootan, E., Nikazar, M., & Arami, M. (2011). Removal of Co (II) from aqueous solution by electrocoagulation process using aluminum electrodes. *Desalination, 279,* 121–126.

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.

Shak, K.P.Y., & Wu, T.Y. (2015). Optimized use of alum together with unmodified Cassia obtusifolia seed gum as a coagulant aid in treatment of palm oil mill effluent under natural pH of wastewater. *Industrial Crops and Products, 76*, 1169–1178.

Shen, J., Zhao, H., Cao, H., Zhang, Y., & Chen, Y. (2014). Removal of total cyanide in coking wastewater during a coagulation process: Significance of organic polymers. *Journal of Environmental Sciences (China), 26,* 231–239.

Sher, F., Malik, A., & Liu, H. (2013). Industrial polymer effluent treatment by chemical coagulation and flocculation. *Journal of Environmental Chemical Engineering, 1,* 684–689.

Solak, M., Kiliç, M., Hüseyin, Y., & Şencan, A. (2009). Removal of suspended solids and turbidity from marble processing wastewaters by electrocoagulation: Comparison of electrode materials and electrode connection systems. *Journal of Hazardous Materials, 172,* 345–352.

Spicer, P.T., & Pratsinis, S.E. (1996). Shear-induced flocculation: The evolution of floc structure and the shape of the size distribution at steady state. *Water Research, 30,* 1049–1056.

Sridhar, R. (2013). *Studies on electrocoagulation technique for treatment of industrial effluents.* (Ph.D. Thesis). Anna University, India.

Sridhar, R., Sivakumar, V., Prakash Maran, J., & Thirugnanasambandham, K. (2014). Influence of operating parameters on treatment of egg processing effluent by electrocoagulation process. *International Journal of Environmental Science and Technology, 11*, 1619–1630.

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.

Tak, B.Y., Tak, B.S., Kim, Y.J., Park, Y.J., Yoon, Y.H., & Min, G.H. (2015). Optimization of color and COD removal from livestock wastewater by electrocoagulation process: Application of Box-Behnken design (BBD). *Journal of Industrial and Engineering Chemistry, 28,* 307–315.

Tatsi, A.A., Zouboulis, A.I., Matis, K.A., & Samaras, P. (2003). Coagulation-flocculation pretreatment of sanitary landfill leachates. *Chemosphere, 53,* 737–744.

Tchamango, S., Nanseu-Njiki, C.P., Ngameni, E., Hadjiev, D., & Darchen, A. (2010). Treatment of dairy effluents by electrocoagulation using aluminium electrodes. *Science of the Total Environment, 408,* 947–952.

Tezcan Un, U., & Aytac, E. (2013). Electrocoagulation in a packed bed reactor-complete treatment of color and cod from real textile wastewater. *Journal of Environmental Management, 123,* 113–119.

Tezcan Un, U., Kandemir, A., Erginel, N., & Ocal, S.E. (2014). Continuous electrocoagulation of cheese whey wastewater: An application of response surface methodology. J *Journal of Environmental Management, 146,* 245–250.

Tezcan Un, U., & Ozel, E. (2013). Electrocoagulation of yogurt industry wastewater and the production of ceramic pigments from the sludge. *Separation and Purification Technology,* 120, 386–391.

Thani, M.I., Hussin, R., Ibrahim, W.R.W., & Sulaiman, M.S. (1999). *Industrial Process and the Environment- Crude Palm Oil Industry, Handbook No. 3.* Malaysia: DOE.

Thirugnanasambandham, K., Sivakumar, V., & Maran, J.P. (2014). Efficiency of electrocoagulation method to treat chicken processing industry wastewater-modeling and optimization. *Journal of the Taiwan Institute of Chemical Engineers, 45,* 2427–2435.

Thirugnanasambandham, K., Sivakumar, V., & Maran, J.P. (2014). Bagasse wastewater treatment using biopolymer – A novel approach. *Journal of the Serbian Chemical Society, 79,* 897–909.

Thirugnanasambandham, K., Sivakumar, V., & Prakasmaran, J. (2015). Optimization of process parameters in electrocoagulation treating chicken industry wastewater to recover hydrogen gas with pollutant reduction. *Renewable Energy, 80,* 101–108.

Tripathy, T., & De, B.R. (2006). Flocculation: A new way to treat the waste water. *Journal of Physical Science, 10,* 93–127.

Uğurlu, M., Gürses, a, Doğar, C., & Yalçin, M. (2008). The removal of lignin and phenol from paper mill effluents by electrocoagulation. *Journal of Environmental Management, 87,* 420–8.

Vepsäläinen, M., Pulliainen, M., & Sillanpää, M. (2012). Effect of electrochemical cell structure on natural organic matter (NOM) removal from surface water through electrocoagulation (EC). *Separation and Purification Technology, 99,* 20–27.

Vik, E.A., Carlson, D.A., Eikum, A.S., & Gjessing, E.T. (1984). Electrocoagulation of potable water. *Water Research, 18,* 1355–1360.

Waite, T.D. (1999). Measurement and implications of floc structure in water and wastewater treatment. *Colloids and Surfaces A: Physicochemical and Engineering Aspects, 151,* 27–41.

Wang, C.T., Chou, W.L., & Kuo, Y.M. (2009). Removal of COD from laundry wastewater by electrocoagulation/electroflotation. *Journal of Hazardous Materials, 164,* 81–86.

Wang, Y., Gao, B.Y., Xu, X.M., Xu, W.Y., & Xu, G.Y. (2009a). Characterization of floc size, strength and structure in various aluminum coagulants treatment. *Journal of Colloid and Interface Science, 332,* 354–359.

Wang, Y., Zhou, W.Z., Gao, B.Y., Xu, X.M., & Xu, G.Y. (2009b). The effect of total hardness on the coagulation performance of aluminum salts with different Al species. *Separation and Purification Technology, 66,* 457–462.

Wang, Z., Nan, J., Yao, M., & Yang, Y. (2017). Effect of additional polyaluminum chloride and polyacrylamide on the evolution of floc characteristics during floc breakage and re-growth process. *Separation and Purification Technology, 173,* 144–150.

Wu, T.Y., Mohammad, A.W., Jahim, J.M., & Anuar, N. (2010). Pollution control technologies for the treatment of palm oil mill effluent (POME) through end-of-pipe processes. *Journal of Environmental Management, 91,* 1467–1490.

Wu, T.Y., Mohammad, A.W., Md. Jahim, J., & Anuar, N. (2007). Palm oil mill effluent (POME) treatment and bioresources recovery using ultrafiltration membrane: Effect of pressure on membrane fouling. *Biochemical Engineering Journal, 35,* 309–317.

Xu, W., Gao, B., Yue, Q., & Wang, Y. (2010). Effect of shear force and solution pH on flocs breakage and re-growth formed by nano-Al13 polymer. *Water Research, 44,* 1893–1899.

Yadav, R. (2010). *Study of electrocoagulation and combined electrocoagulation-oxidation processes for dye removal.* (Ph.D. Thesis). Thapar University, India.

Yang, B., Han, Y., Deng, Y., Li, Y., Zhuo, Q., & Wu, J. (2016). Highly efficient removal of perfluorooctanoic acid from aqueous solution by H2O2-enhanced electrocoagulation-electroflotation technique. *Emerging Contaminants, 2,* 49–55.

Yean, P., & Dong, Z. (2014). Econometric study on Malaysia's palm oil position in the world market to 2035. *Renewable and Sustainable Energy Reviews,39,* 740–747.

Zaidi, S., Chaabane, T., Sivasankar, V., Darchen, A., Maachi, R., Msagati, T.A.M., & Prabhakaran, M. (2016). Performance efficiency of electro-coagulation coupled electro-flotation process (EC-EF) versus adsorption process in doxycycline removal from aqueous solutions. *Process Safety and Environmental Protection, 102,* 450–461.

Zaied, M., & Bellakhal, N. (2009). Electrocoagulation treatment of black liquor from paper industry. *Journal of Hazardous Materials, 163,* 995–1000.

Zhao, S., Gao, B., Li, X., & Dong, M. (2012). Influence of using *Enteromorpha* extract as a coagulant aid on coagulation behavior and floc characteristics of traditional coagulant in Yellow River water treatment. *Chemical Engineering Journal, 200–202,* 569–576.

Zhao, Y.X., Gao, B.Y., Rong, H.Y., Shon, H.K., Kim, J.H., Yue, Q.Y., & Wang, Y. (2011). The impacts of coagulant aid-polydimethyldiallylammonium chloride on coagulation performances and floc characteristics in humic acid-kaolin synthetic water treatment with titanium tetrachloride. *Chemical Engineering Journal, 173,* 376–384.

Zinatizadeh, A.A.L., Mohamed, A.R., Abdullah, A.Z., Mashitah, M.D., Isa, M.H., & Najafpour, G.D. (2006). Process modeling and analysis of palm oil mill effluent treatment in an up-flow anaerobic sludge fixed film bioreactor using response surface methodology (RSM). *Water Research, 40,* 3193–3208.