UNIVERSITI PUTRA MALAYSIA

UTILIZATION AND OPTIMIZATION OF INDUSTRIAL BOTTOM ASH FOR PALM OIL MILL EFFLUENT DECOLOURIZATION

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By

SYAHIN BT MOHAMMAD SALEH

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

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Chair : Assoc. Prof. Ir. Wan Azlina Wan Abdul Karim Ghani, PhD
Faculty : Engineering

The increasing demand of crude palm oil (CPO) has resulted in the enormous increases in palm oil mills operation in Malaysia and hence the palm oil mill effluent (POME) discharges. Thus, existing treatment facilities have difficulties to comply the discharge limit for this excess POME from the running plants. In this case, colour of POME was one of the major concerns as it will be incorporated in the current regulation. Various adsorbents (i.e POMBA, treated POMBA, CBA, treated PKS) had been screened for POME decolourization. Coal bottom ash (CBA) showed highest colour removal percentage among others and hence selected for the consequence investigations. The raw CBA were then chemically (ACBA) and physically treated (PCBA) for comparison study. Furthermore, response surface methodology (RSM) was used for optimization. As results, the optimum parameters of ACBA and PCBA for POME colour adsorption proposed the followings: 14.20 hr and 15.37 hr contact time, 13.16 g and 13.84 g adsorbent dosage, 27.97% and 57.52% POME concentration, pH 6.24 and pH 6.04, respectively. Both predicted and experimental percentage removal of POME colour for ACBA and PCBA were significantly correlated with the R^2 values for ACBA and PCBA were 0.9793 and 0.9755, respectively. Physico-chemical characterizations of both treated CBA were performed using BET for surface area, FTIR for its surface chemistry, SEM for morphology and EDX for elemental analysis. It was shown that the isotherms for adsorption of colour from POME onto treated CBA were well fitted by Freundlich model. Furthermore, pseudo-second order was identified to be governing mechanism for both treated CBA. Other pollutants i.e COD, BOD_3 and NH_3-N removal are also evaluated. It was found that percentage removal of COD, BOD_3 and NH_3-N using ACBA were 61.33%, 58.33% and 61.43%, respectively. Meanwhile, percentage removal of COD, BOD_3 and NH_3-N using PCBA were 38.39%, 33.33% and 31.10%, respectively. Upon these findings, CBA has potential not only in POME decolourization also in POME treatment as adsorbent.

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PENGGUNAAN DAN PENGOPTIMUMAN ABU MENDAP DARI INDUSTRI UNTUK MENYAHWARNA SISA KILANG MINYAK KELAPA SAWIT

Oleh

SYAHIN BT MOHAMMAD SALEH

Januari 2019

Pengerusi : Profesor Madya Ir. Wan Azlina Wan Abdul Karim Ghani, PhD
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Peningkatan permintaan minyak kelapa sawit mentah (CPO) meningkatkan operasi kilang minyak kelapa sawit di Malaysia dan begitu juga penjanaan sisa kilang minyak kelapa sawit (POME). Oleh itu, kemudahan rawatan yang sedia ada mempunyai kesulitan untuk mematuhi had pelepasan untuk POME yang berlebihan keluar daripada kilang yang sedang beroperasi. Dalam kes ini, warna POME adalah salah satu kebimbangan utama kerana ia akan dimasukkan ke dalam peraturan semasa. Pelbagai penyerap (i.e POMBA, POMBA dirawat, CBA, PKS dirawat) telah diskrin untuk menyahwarnakan POME. Abu mendap arang (CBA) menunjukkan peratusan pernyingkiran warna yang paling tinggi antara yang lain dan dengan itu ia dipilih untuk akibat penyelidikan. CBA mentah dirawat kimia (ACBA) dan dirawat secara fizikal (PCBA) untuk kajian perbandingan. Tambahan pula, metodologi tindak balas permukaan (RSM) digunakan untuk pengotimuman.Sebagai hasilnya parameter optimum ACBA dan PCBA untuk menyahwarnakan POME mencadangkan: 14.20 jam dan 15.37 jam masa sentuhan, 13.16 g dan 13.84 g dos penjerap, 27.97% dan 57.52% kepekatan POME, pH 6.24 dan pH 6.04. Kedua-dua ramalan dan percubaan penyingkiran warna POME untuk ACBA dan PCBA berkorelasi dengan nilai R^2 untuk ACBA dan PCBA masing-masing adalah 0.9793 dan 0.9755. Pengelasan fiziko-kimia kedua-dua CBA yang dirawat telah dibuat dengan menggunakan BET untuk menganalisa luas permukaan, FTIR untuk kimia permukaannya, SEM untuk morfologi dan EDX untuk analisis unsur. Telah ditunjukkan bahawa isotem untuk menyahwarnakan POME pada CBA yang dirawat telah sesuai dengan model Freundlich. '*Pseudo second order*' telah dikenalpasti sebagai mekanisme yang dikawal bagi kedua-dua CBA yang dirawat. Penghapusan bahan pencemar lain seperti COD, BOD_3 dan NH_3-N juga dinilai. Telah didapati bahawa penghapusan COD, BOD_3 dan NH_3-N menggunakan ACBA masing-masing adalah 61.33%, 58.33% dan 61.43%. Manakala, penghapusan COD, BOD_3 dan NH_3-N menggunakan PCBA masing-masing adalah 38.39%, 33.33% dan 31.10%. Atas penemuan ini, CBA mempunyai potensi bukan sahaja dalam penyahwarna POME malah juga dalam rawatan POME sebagai penjerap.

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I certify that a Thesis Examination Committee has met on 7 January 2019 to conduct the final examination of Syahin binti Mohammad Saleh on her thesis entitled "Utilization and Optimization of Industrial Bottom Ash for Palm Oil Mill Effluent Decolourization" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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This is to confirm that:

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LIST OF ABBREVIATIONS

A.P.	Adequate precision
AAm	Acrylamide
ABA	Acid treated BA
AC	Activated carbon
Adj. R^2	Adjusted R^2
ADMI	American Dye Manufacturers Institute
ANOVA	Analysis of variance
AnPOME	Anaerobically treated effluent
APS	Ammonium persulfate
As	Arsenic
BET	Brunauer-Emmett-Teller
BOD	Biochemical oxygen demand
C	Final concentration
C.V.	Coefficient of variance
CaO	Calcium oxide
CBA	Coal bottom ash
CBZ	Carbamazepine
CCD	Central composite design
C_e	Concentration at equilibrium
C_o	Initial concentration
CO_2	Carbon dioxide
COD	Chemical oxygen demand
CPO	Crude palm oil
C_t	Concentration at t
DOE	Department of environment
DOE	Design of experiment
DW	Distilled water
EDX	Energy Dispersive X-Ray
FA	Fly ash
$FeCl_3$	Iron chloride
FFB	Fresh fruit bunches
FTIR	Fourier Transform Infrared
H_2O_2	Hydrogen peroxide
H_2SO_4	Sulphuric acid
H_3PO_4	Phosphoric acid
HBC-POMBA	Hydrogel biochar palm oil mill boiler ash composite
HCl	Hydrochloric acid
HNO_3	Nitric acid
k	Number of variables
K_1	First order rate constant
K_2	Second order rate constant
K_F	Constant related to the overall adsorption capacity
K_L	Langmuir isotherm constant
KOH	Potassium hydroxide
M	Molar concentration
m	Mass
MBA	N,N'-Methylenebisacrylamide

$MgCl_2 \cdot 6H_2O$	Magnesium chloride hexahydrate
MgO	Magnesium oxide
N	Normality
N_2	Nitrogen gas
NaOH	Sodium hydroxide
NH_3-N	Ammonical-nitrogen
P (AAm)	Poly(acrylamide)
Pb	Lead
PBA	Pyrolysis treated BA
PES	Polyethersulphone
PKS	Palm kernel shell
PKSAC	Palm kernel shell activated carbon
POMBA	Palm oil mill boiler ash
POME	Palm oil mill effluent
Pre. R^2	Predicted R^2
Pt-Co	Platinum-cobalt
PVDF	Polyvinylidene fluoride ultrafitration
q_e	Amount of adsorbate adsorbed by adsorbent at equilibrium
q_{max}	Maximum amount of adsorbate adsorbed by adsorbent
q_t	Amount of adsorbate adsorbed at time t
R^2	Coefficient of determination
R^2	Correlation coeffiecient
rpm	Rotation per minute
RSM	Response surface methodology
SEM	Scanning Electron Mscroscope
SMX	Sulfamethoxazole
t	Time
TiO_2	Titanium dioxide
UBA	Untreated BA
V	Volume of solution
x_i	Independent variables
x_j	Independent variables
Y	Predicted response
ZIO	Zinc-iron oxide
Zn	Zinc
$ZnCl_2$	Zinc Chloride
α_0	Coefficient of constant
α_i	Coefficient of linear
α_{ii}	Coefficient of squared
α_{ij}	Coefficient of cross-product
ε_0	Measurement error.

CHAPTER 1

INTRODUCTION

1.1 Research Background

Water crisis is an alarming issues worldwide due to clean water is getting deteriorate. Disposal of wastewater from industrial and commercial sources grab a lot of attention from people and government because it may contain pollutants at levels that could have an impact on environmental conditions of receiving waters. It may cause adverse impacts such as water pollution, creating unpleasant smells and potential health hazard. Commonly, the water discharging from industrial wastes have the most intense coloring i.e. textile industry, paper industry, food industry, and palm oil industry. Colour of surface water is a sign of pollution by the public (Zahrim *et al*., 2014). Colour in water may appear faulty to human because the colour makes it unappealing to drink. It also affects aquatic plant due to the colour reduces photosynthesis activity and dissolved oxygen (Ratpukdi *et al*., 2012). In general, suspended and dissolved particles in water influence colour which may be the result of natural causes or/and human activity. Low accumulation of dissolved materials appears as transparent water and showing low productivity. Moreover, dissolved organic matter, such as peat, humus or decaying plant matter may produce a yellow or brown colour (Perlman, 2016). Different colour of surface water influenced by different sources for instance tannin contributes to the brown colour of the water caused by organic matter coming out from leaves and roots. Palm oil industry is commonly discharging brown colour due to lignin and tannin producing from plants such as oil palm fruits, leaves, root and etc. It was reported that the content of lignin in waste palm shells is 50.7% (Kong *et al*., 2014). Colour of POME still remains even after biological treatment, both aerobic and anaerobic process (Mohammed *et al*., 2014). Even, new and advanced technologies available in the market which are ultrafiltration, membrane bioreactor, coagulation treatment and sequencing batch reactor still the water discharged is brownish and visible in water stream (Jalani *et al*., 2016). Colour pigments are highly stable and resistant to light and moderate oxidative agents, thus they cannot be fully removed by a conventional biological treatment such as activated sludge and anaerobic digestion (Vimonses *et al*., 2009). The palm oil industry has felt uncomfortable tackling issue on this colour removal from POME since it is difficult to be removed. This has drawn the attention of researchers to study on removing them from POME.

Effluent standards regarding to colour level have been applied under Environmental Quality (Industrial Effluent) Regulation 2009. According to the fifth schedule under Environmental Quality (Industrial Effluent) Regulation 2009, level of colour cannot be discharged more than 100 American Dye Manufacturers Institute (ADMI) units (Environmental Quality Act 1974). If the level of the colour discharge exceeds the standard, then it is considered as water pollution. Clean and safe water is needed to be the concern on in order to avoid any environmental and human health impact and of course to save it for future generation as well as gain greener image for our country. Otherwise, polluted water is ingested by people may ill and with prolonged exposure, it may develop cancers or bear children with birth defects. The major water pollutants are chemical, biological, or physical materials which degrade water quality. There are several methods to treat wastewater such as adsorption (Popuri *et al.*, 2016), flocculation and coagulation (Madhavi *et al.*, 2014), ozonation (Mustapha, 2015), oxidation (Hassaan *et al.*, 2017), membrane filtration (Zielińska and Galik, 2017) and microbial biodegradation (Selvakumar *et al.*, 2013). Among these methods, adsorption technique seems to be an effective alternative for removal of water pollutants. Activated carbon has been used widely as the adsorbent in adsorption of organic substances including dyes and colours due to its high adsorption capacity and high surface area (Tan *et al.*, 2015). Despite its prolific use in water and wastewater industries, commercial activated carbon application is still limited due to its high cost and difficulty in regeneration (Sun *et al.*, 2012). This has led to a search for low cost materials as an alternative adsorbent. Several studies reported on alternative low cost adsorbents for colours removal from wastewater i.e. activated carbon prepared from coconut shell (Sia *et al.*, 2017), orange peel (Popuri *et al.*, 2016), palm kernel shell (Jalani *et al.*, 2016), almond gum (Bouaziz *et al.*, 2015), fly ash (Asadullah and Rathnasiri, 2015) and sepiolite (Duman *et al.*, 2015). Based on the usage of widely available and low-cost materials recovered from waste, study becomes more interesting that has been eco-friendly approach of ''using waste to treat the waste" by adsorption for removal of hazardous pollutants from solution, instead of using expensive adsorbents (e.g. ion exchange resins or commercial activated carbon).

Coal bottom ash is a waste material produced from combustion of solid fuels. It is incombustible waste material of thermal power plant collected from the bottom of the incinerator furnace (Mittal *et al.*, 2013). Recently, a number of studies have shown that bottom ash is used as potential low cost adsorbent to remove many types of dyes such as vertigo blue dyes (Kusmiyati *et al.*, 2017), basic dyes (Gandhimathi *et al.*, 2013), eosin yellow dye (Mittal *et al.*, 2013), congo red (Saleh *et al.*, 2012) and crystal violet (Nisheesh *et al.*, 2012). This is due to the characteristic of CBA which its particle size span, high porosity and large surface area (Cahan *et al.*, 2013). There is no literature on the removal of colour from POME so far by using CBA as an adsorbent. This suggests that CBA may have the potential to remove colour from POME under different pH, initial POME concentration, adsorbent dosage and contact time. It is abundantly available since it is an incombustible waste material of thermal power plant (Mittal *et al.*, 2013). Disposal of CBA becomes an issue because it requires a larger area for disposal due to increasing generation of CBA waste (Jayaranjan *et al*, 2014). Therefore, the practical use of CBA shows a great contribution to waste minimization as well as resources conservation.

Besides that, a few studies have paid attention to chemical/physical treatment for the adsorbent to enhance the adsorption capacity of adsorbents. This is because adsorbents come from different raw material will give different adsorption capacity. Treatment is necessary in order to achieve optimum adsorption. Treatments of low-cost adsorbent those have been studied includes steam activation of palm kernel shell (Jalani *et al.*, 2016), acid activation of fly ash (Asadullah and Rathnasiri, 2015), acid activation of coal bottom ash (Jarusiripot, 2014) and alkaline treatment of biomass fly ash (Pengthamkeerati *et al.*, 2010). Some of the studies, chemical and physical treatment was combined to activate the adsorbent such as microwave and chemical activation of palm kernel shell and empty fruit bunch (Mohammed *et al*, 2013), and alkali activation followed by pyrolysis of peanut shell, corncob and cotton stalks biochars (Liu *et al*., 2016).

1.2 Problem Statement

Coloured water when it is discharged into surface water, the natural colour of the water will change. It does not only reduce water clarity, making aquatic life difficult to find food, also prevent the transmission of sunlight through the water. This causes aquatic plants such as sea-grasses and seaweed do not have enough sunlight for their photosynthesis process which their function is served as nurseries for many important fish species. The problem arises when a lot of industrial wastewaters contain substances that are difficult to remove through conventionally secondary treatment.

The increasing production of major oil palm products generates a high amount of palm oil mill effluent (POME) as a potential environmental pollutant requiring urgent attention due to its considerably "stubborn" color characteristics. This is because even after tertiary treatment, colour still remains. The effluent colour is primarily due to lignin and its degraded products, which chemically stable and resistant to biological degradation. Besides, the treatment conducted by using membrane bioreactor has successfully removed the heavy organic component of POME, however, the discharged water remains coloured due to its by-products (Facta *et al*., 2010). Another study has mentioned that a high COD can be removed using membrane anaerobic system, however, the permeate shows a high colour with low turbidity (< 10 NTU) due to dissolved solids content with molecular weights < 200,000 g/mol (Wu *et al*., 2010). Figure 1.1 show the final discharge of POME at Maran, Pahang. Even after ponding treatment, the dark brown colour still remained.

Figure 1.1: Final discharge of POME in Maran, Pahang

Coal bottom ash disposal is abundant as tonnes of CBA are generated daily and end up in near the surrounding land either as wet or dry form. It is produced approximately 25% from coal combustion and it is not widely utilized in Malaysia (Marto and Tan, 2016). The massive generation of CBA results in handling and storage problems such as inadequate facilities or spaces to hold the residues, hence contributes to high capital and operating cost (Rashidi and Yusop, 2016; Jayaranjan *et al*, 2014). It also became authorities concern since its disposal makes the land infertile and is considered unsuitable for agricultural utilization (Nisheesh *et al*., 2012). Power plants stations that located near to urban cities will face difficulties in finding appropriate disposal sites. Thus, an attempt to find an alternative way of CBA utilization is necessary in order to reduce waste disposal and avoid the consumption of increasingly scarce landfill space.

1.3 Research Objectives

The objective of this study is to find an effective and low-cost adsorbent, and to evaluate its potential to remove colour from palm oil mill effluent (POME). The specific objectives of this research include:

1. To assess the physico-chemical properties of coal bottom ash (CBA) and treated CBA as a potential adsorbent. (SEM, EDX, FTIR, BET)
2. To evaluate and optimize treated CBA in colour removal from POME using response surface methodology.
3. To perform the adsorption isotherm and kinetics study of treated CBA adsorption for POME colour removal using Langmuir and Freundlich; Pseudo-first-order and Pseudo-second-order.

1.4 Scope of Research

This research was carried out to evaluate the potential of adsorbent that able to remove colour from POME. Various adsorbents had been screening in order to select the best performance for POME decolourization. Coal-fired plant bottom ash was selected as a potential adsorbent for POME decolourization and was further discussed in this study including adsorbent treatment and optimization. Raw material which was CBA was taken from the local power plant, Stesen Janakuasa Sultan Azlan Shah, Manjung, Perak. CBA was pretreated by rinsing with distilled water several times and drying in an oven at 70℃ for two days. CBA was treated by physical and chemical treatment, respectively. CBA was pyrolyzed with the flowing of nitrogen gas (N_2) at 700 ℃ for 1 hr and was denoted as PCBA. Meanwhile, for chemical treatment, CBA was treated with acid by stirring it with 0.1 M HCl for 24 hours and was left for overnight, later it was rinsed with an excess of distilled water to obtain pH 7. It was denoted as ACBA. Both treated CBA was dried in an oven at 70˚C for two days. Later, samples of CBA were taken into analysis for characterization. The analysis that had been done was Braunauer-Emmeh-Teller (BET) surface area, Scanning Electron Microscope (SEM), Fourier Transform Infrared Spectroscopy (FTIR), and Energy Dispersive X-Ray analysis (EDX). POME sample was prepared by filtering it through filter paper to remove solids following the APHA platinum-cobalt standard method. The sample of POME was taken from Kilang Sawit Sri Senggora, Maran, Pahang. The performance of colour adsorption onto treated CBA was analyzed using spectrophotometer (HACH DR2700) in unit PtCo by measuring the percentage removal. It was analyzed before and after the adsorption process. Optimization was performed using response surface methodology (RSM) to find optimal values to achieve maximum removal. Isotherm and kinetic study were also studied. Other pollutants removal (i.e. COD, BOD_3 and NH_3-N) by using ACBA and PCBA, respectively were also evaluated following the optimization condition of colour removal.

1.5 Significant Contribution

The main contribution of this research is to observe the ability and potentiality of treated coal-fired plant bottom ash to decolourize palm oil mill effluent (POME). This study targets for POME pollution abatement to promote a greener image of the palm oil industry. It also offers the palm oil industry an insight for better effluent management. Besides, the utilization of CBA through this study may contribute to reducing the waste disposal. It has been eco-friendly approach of "using waste to treat another waste" instead of using expensive adsorbent.

1.6 Limitation of Study

Limitation of this study is there is no literature on POME decolourization by CBA as potential adsorbent and there is also limited information on adsorption behavior of POME colour onto the adsorbent. Thus, the properties and characteristic of CBA contributing to adsorption of colour from POME are evaluated throughout this study. This study focuses on utilization of CBA as a potential adsorbent for POME decolourization. Colour of wastewater is quite complicated since it is composed of various components. Hence, this study focuses on colour reduction of POME using CBA by measuring the colour before and after treatment following APHA platinum-cobalt standard method.

REFERENCES

Abdullah, N., & Sulaiman, F. (2013). The Oil Palm Wastes in Malaysia. In M. D. Matovic (Ed.), *Biomass Now - Sustainable Growth and Use*: InTech Publisher.

Abdurahman, N. H., Azhari, H. N., & Said, N. (2017). An integrated ultrasonic membrane an aerobic system (IUMAS) for palm oil mill effluent (POME) Treatment. *Energy Procedia,* 138: 1017-1022.

Abubakar, A. U., & Baharudin, K. S. (2012). Potential use of Malaysian thermal power plants coal bottom ash in construction. *International Journal of Sustainable Construction Engineering & Technology,* 3(2): 25-37.

Adeleke, A. O., Latiff, A. A. A., Al-Gheethi, A. A., & Daud, Z. (2017). Optimization of operating parameters of novel composite adsorbent for organic pollutants removal from POME using response surface methodology. *Chemosphere,* 174: 232-242.

Ademiluyi, F. T., & David-West, E. O. (2012). *Effect of Chemical Activation on the Adsorption of HeavyMetals Using Activated Carbons from Waste Materials*. Paper presented at International Scholarly Research Network ISRN Chemical Engineering (2012), 1-5.

Ahmad, A. L., & .Chan, C.Y. (2009). Sustainability of palm oil industries: an innovative treatment via membrane technology. *Journal of Applied Science* (9): 3074-3079.

Ahmad, A. L., Chong, M. F., Bhatia, S., & Ismail, S. (2006). Drinking water reclamation from palm oil mill effluent (POME) using membrane technology. *Desalination,* 191: 35-44.

Ai, T. Y., Kuntom, A., Lin, S. W., Yusof, M., & Let, C. C. (2000). *PORIM technology*.

Al-Hamadani, Y. A. J., Park, C. M., Assi, L. N., Chu, K. H., Hoque, S., Jang, M & Ziehl, P. (2017). Sonocatalytic removal of ibuprofen and sulfamethoxazole in the presence of different fly ash sources. *Ultrasonics Sonochemistry,* 39: 354-362.

Amat, N. A., Tan, Y. H., Lau, W. J., Lai, G. S., Ong, C. S., Mokhtar, N. M., Sani, N. A. A., Ismail, A. F., Goh, P. S., Chong, K. C., & Lai, S. O. (2015). Tackling colour issue of anaerobically-treated palm oil mill effluent using membrane technology. *Journal of Water Process Engineering,* 8: 221-226

Asadullah, & Rathnasiri, P. G. (2015). Optimization of adsorption-coagulation process for treatment of palm oil mill effluent (POME) using alternative coagulant. *International Research Symposium on Engineering Advancements*. 68-71.

Asokbunyarat, V., Hullebusch, E. D. v., Lens, P. N. L., & Annachhatre, A. P. (2015). Coal bottom ash as sorbing material for Fe(II), Cu(II), Mn(II) and Zn(II) removal from aqueous solution. *Water Air Soil Pollution,* 226: 1-17.

Ayala, J., & Fernandez, B. (2016). A case study of landfill leachate using coal bottom ash for the removal of Cd(II), Zn(II) and Ni(II). *Metals,* 6(300): 1-15.

Ayob, A., Zahid, M. Z. A. M., Zaki, M. F. M., Hamid, S. H. A., Yussuf, M. A.-H. M., & Yunus, A. N. M. (2014). *Physical, morphological and strength properties of Jana Manjung coal ash mixture for geotechnical applications*. Paper presented at Conference: 4th International Malaysia-Irenland Joint Symposium on Engineering, Science and Business.

Azmi, N. B., Bashir, M. J. K., Sethupathi, S., Wei, L. J., & Aun, N. C. (2015). Stabilized landfill leachate treatment by sugarcane bagasse derived activated carbon for removal of color, COD and NH_3-N – Optimization of preparation conditions by RSM. *Journal of Environmental Chemical Engineering,* 3(2): 1287-1294.

Bala, T., Prasad, B. L. V., Sastry, M., Kahaly, M. U., & Waghmare, U. V. (2007). Interaction of different metal ions with carboxylic acid group: A quantitative study. *The Journal of Physical Chemistry A,* 111(28): 6183-6190.

Banerjee, S., & Chattopadhyaya, M. C. (2017). Adsorption characteristics for the removal of a toxic dye, tartrazine from aqueous solutions by a low cost agricultural by-product. *Arabian Journal of Chemistry,* 10(2): 1629-1638.

Bashir, M. J. K., Han, T. M., Wei, L. J., Aun, N. C., & Amr, S. S. A. (2016). Polishing of treated palm oil mill effluent (POME) from ponding system by electrocoagulation process. *Water Science & Technology,* 73(11): 2704-2712.

Bashir, M. J. K., Wei, C. J., Aun, N. C., & Abu Amr, S. S. (2017). Electro persulphate oxidation for polishing of biologically treated palm oil mill effluent (POME). *Journal of Environmental Management,* 193: 458-469.

Basu, P. (2013). *Biomass Gasification, Pyrolysis, and Torrefaction* (Second ed.). United States of America: Elsevier.

Behera, S. K., Meena, H., Chakraborty, S., & Meikap, B. C. (2018). Application of response surface methodology (RSM) for optimization of leaching parameters for ash reduction from low-grade coal. *International Journal of Mining Science and Technology*. 28(4): 621-629.

Bello, M. M., Abdullah, L. C., & Norzaei, M. (2013a). Color and COD Removal from Palm Oil Mill Effluent (POME) using Resin: Fixed-bed Column Adsorption. *Proceeding of the International Conference Biotechnology Engineering, ICBioE*, 45-50.

Bello, M. M., Nourouzi, M. M., Abdullah, L. C., Choong, T. S. Y., Koay, Y. S., & Keshani, S. (2013b). POME is treated for removal of color from biologically treated POME in fixed bed column: Applying wavelet neural network (WNN). *Journal of Hazardous Materials,* 262: 106– 113.

Boehm, H. P. (1994). Some aspects of the surface chemistry of carbon blacks and other carbons. *Carbon,* 32(5): 759-769.

Bouaziz, F., Koubaa, M., Kallel, F., Chaari, F., Driss, D., Ghorbel, R. E., & Chaabouni, S. E. (2015). Efficiency of almond gum as a low-cost adsorbent for methylene blue dye removal from aqueous solutions. *Industrial Crops and Products,* 74: 903-911.

Budi, E., Umiatin, Nasbey, H., Bintoro, R. A., Wulandari, F., & Erlina. (2016). Activated coconut shell charcoal carbon using chemical physical activation. *2nd Padjadjaran International Physics Symposium 2015*, 1-5.

Camacho, L. M., Ponnusamy, S., Campos, I., Davis, T. A., & Deng, S. (2015). 5 - Evaluation of novel modified activated alumina as adsorbent for arsenic removal A2 - Flora, S.J.S *Handbook of Arsenic Toxicology* (pp. 121-136). Oxford: Academic Press.

Chaudhari, P. K., Majumdar, B., Choudhary, R., Yadav, D. K., & Chand, S. (2010). Treatment of paper and pulp mill effluent by coagulation. *Environmental Technology,* 31(4): 357-363

Chen, X., Si, C., & Fatehi, P. (2018). Enhancement in biological treatment of pulping wastewater by fly ash. *Chemosphere, 210*: 1-9.

Cho, Y. M., Werner, D., Janssen, E. M. L., & Luthy, R. G. (2014). *In Situ Treatment for Control of Hydrophobic Organic Contaminants Using Sorbent Amendment:Theoretical Assessment.* New York.

Cibati, A., Foereid, B., Bissessur, A., & Hapca, S. (2017). Assessment of *Miscanthus* × *Giganteus* derived biochar as copper and zinc adsorbent: Study of the effect of pyrolysis temperature, pH and hydrogen peroxide modification. *Journal of Cleaner Production,* 162: 1285-1296.

Danish, M., Hashim, R., Ibrahim, M. N. M., & Sulaiman, O. (2013). Effect of acidic activating agents on surface area and surface functional groups of activated carbons produced from *Acacia* mangium wood. *Journal of Analytical and Applied Pyrolysis,* 104: 418-425.

Darajeh, N., Idris, A., Masoumi, H. R. F., Nourani, A., Truong, P., & Sairi, N. A. (2016). Modeling BOD and COD removal from palm oil mill secondary effluent in floating wetland by C*hrysopogon Zizanioides* (l.) using response surface methodology. *Journal of Environmental Management,* 181: 343-352.

Davarnejad, R., Moraveji, M. K., & Havaie, M. (2018). Integral technique for evaluation and optimization of Ni (II) ions adsorption onto regenerated cellulose using response surface methodology. *Arabian Journal of Chemistry,* 11(3): 370-379.

De Gisi, S., Lofrano, G., Grassi, M., & Notarnicola, M. (2016). Characteristics and adsorption capacities of low-cost sorbents for wastewater treatment: A review. *Sustainable Materials and Technologies,* 9: 10-40.

Demirbas, E., Kobya, M., & Sulak, M. T. (2008). Adsorption kinetics of a basic dye from aqueous solutions onto apricot stone activated carbon. *Bioresource technology,* 99(13): 5368-5373.

Department of Environment. (2010). *Environmental Requirements: A Guide For Investors*. Eleventh edition.

Dinçer, A. R., Güneş, Y., Karakaya, N., & Güneş, E. (2007). Comparison of activated carbon and bottom ash for removal of reactive dye from aqueous solution. *Bioresource technology,* 98(4): 834-839.

Dulger, A., & Yilmaz, E. (2013). Effectiveness of modified zeolites as adsorbent materials for frying oils. *European Journal of Lipid Science and Technology,* 115: 668-675.

Duman, O., Tunç, S., & Gürkan Polat, T. (2015). Adsorptive removal of triarylmethane dye (Basic Red 9) from aqueous solution by sepiolite as effective and low-cost adsorbent. *Microporous and Mesoporous Materials,* 210: 176-184.

Dutka, M., Ditaranto, M., & Løvås, T. (2015). Application of a central composite design for the study of NOx emission performance of a low NOx burner. *Energies,* 8: 3606-3627.

Elmi, H. S. A., Nor, M. H. M., & Ibrahim, Z. (2015). Colour and COD removal from palm oil mill effluent (POME) using *Pseudomonas Aeruginosa* strain NCIM 5223 in microbial fuel cell. *International Journal of Waste Management Journal,* 5(3): 1-3.

Facta, M., Salam, Z., Buntat, Z., & Yuniarto, A.. *Silent discharge ozonizer for colour removal of treated palm oil mill effluent using a simple high frequency resonant power converter.* Paper presented at IEEE International Conference on Power and Energy, 2010.

Fawzan, A. A. (2010). *Bottom Ash as a sand replacement in concrete mix*. Master Thesis. KLIUC, Malaysia.

Fermoso, J., Gil, M. V., Arias, B., Plaza, M. G., Pevida, C., Pis, J. J., & Rubiera, F. (2010). Application of response surface methodology to assess the combined effect of operating variables on high-pressure coal gasification for H_2-rich gas production. *International Journal of Hydrogen Energy,* 35(3): 1191-1204.

Fosso-Kankeu, E., Waanders, F. B., Grobler, I. M., & Lemmer, N. (2016). *Synthesis and application of hydrogel-silica composite for the removal of lead from aqueous solution*. Paper presented at International Conference on Advances in Science, Engineering, Technology and Natural Resources, 106-109.

Gandhimathi, R., Ramesh, S. T., Sindhu, V., & Nidheesh, P. V. (2013). Bottom ash adsorption of basic dyes from their binary aqueous solutions. *Songklanakarin Journal of Science and Technology,* 35(3): 339-347.

Geankoplis, C. J. (2003). *Transport Processes and Separation Process* (Fourth ed.). United States: Pearson Education International.

Genuino, D. A. D., de Luna, M. D. G., & Capareda, S. C. (2018). Improving the surface properties of municipal solid waste-derived pyrolysis biochar by chemical and thermal activation: Optimization of process parameters and environmental application. *Waste Management,* 72: 255-264

Ghani, Z. A., Yusoff, M. S., Zaman, N. Q., Zamri, M. F. M. A., & Andas, J. (2017). Optimization of preparation conditions for activated carbon from banana pseudo-stem using response surface methodology on removal of color and COD from landfill leachate. *Waste Management,* 62: 177-187.

Gordon. (2013). What scale is used to measure the color of waste water?. Retrieved 28 December 2017 from https://measuretruecolor.hunterlab.com/2013/03/01/true-color-apparent-color-adams-nickerson-biodegradable-colour-admi-color-of-waste-water/

Gorme, J. B., Maniquiz, M. C., Kim, S. S., Son, Y. G., Kim, Y. T., & Kim, L. H. (2010). Characterization of bottom ash as an adsorbent of lead from aqueous solutions. *Environmental engineering Research,* 15(4): 207-213.

Grabowska, E. L., & Gryglewicz, G. (2007). Adsorption characteristic of Congo Red on coal-based mesoporous activated carbon. *Dye and Pigments,* 74: 34-40.

Guidelines, A. D. W. (2013). Colour (True). Retrieved 13 February 2018 from https://www.clarence.nsw.gov.au/page.asp?f=RES-WHM-86-71-52

Gun'ko, V. M., Matkovsky, A. K., Charmas, B., Zięba, J. S., & Pasieczna-Patkowska, S. (2017). Carbon–silica gel adsorbents. *Journal of Thermal Analysis and Calorimetry,* 128(3): 1683-1697.

HACH. (2016). What is the meaning of ADMI. Retrieved 18 September 2017 from https://support.hach.com/app/answers/answer_view/a_id/1000980/~/what-is-the-meaning-of-admi%3F-

Han, Y.W., Lee, J.S., Anderson, A.W., (1975). Chemical composition and digestibility of rye grass straw. *Journal of Agriculture and Food Chemistry,* 23: 928-931.

Han, T. M. (2015). *Electro oxidation of palm oil mill effluent (POME): Post treatment* Master Thesis. Universiti Tunku Abdul Rahman, Selangor.

Hariani, P. L., Faizal, M., Ridwan, Marsi, & Setiabudidaya, D. (2018). Removal of Procion Red MX-5B from songket's industrial wastewater in South Sumatra Indonesia using activated carbon-Fe_3O_4 composite. *Sustainable Environment Research,* 28(4): 158-164.

Hasan, M., Ahmad, A. L., & Hameed, B. H. (2008). Adsorption of reactive dye onto cross-linked chitosan/oil palm ash composite beads. Chemical Engineering Journal, 136: 164-172.

Hassan, S., Kee, L. S., Hussain, H., & Kayiem, A. (2013). Experimental study of palm oil mill effluent and oil palm frond waste mixture as an alternative biomass fuel *Journal of Engineering Science and Technology,* 8(6): 703-712.

Hassaan, M. A., El Nemr, A., & Madkour, F. F. (2017). Testing the advanced oxidation processes on the degradation of Direct Blue 86 dye in wastewater. *The Egyptian Journal of Aquatic Research,* 43(1): 11-19.

Hibbins, A. R., Kumar, P., Choonara, Y. E., Kondiah, P. P. D., Marimuthu, T., Toit, L. C. d., & Pillay, V. (2017). Design of a versatile ph - responsive hydrogel for potential oral delivery of gastric-sensitive bioactives. *Polymers,* 9(474): 1-18.

Hickel, W. J. (1969). *Quality of Surface Waters of the United States*. California: United States Government Printing Office, Washington

Ho, C.C., Tan, Y.K., & Wang C.W., (1984). The distribution of chemical constituents between the soluble and the particulate fractions of palm oil mill effluent and its significance on its utilization/treatment. *Agriculture Wastes,*11: 61-71.

Hong, J. K., Jo, H. Y., & Yun, S. T. (2009). Coal fly ash and synthetic coal fly ash aggregates as reactive media to remove zinc from aqueous solutions. *Journal of Hazardous Materials,* 164(1): 235-246.

Huff, M. D., & Lee, J. W. (2016). Biochar-surface oxygenation with hydrogen peroxide. *Journal of Environmental Management,* 165: 17-21.

Ibrahim, A. H., Ridwan, M. F., Abidin, C. Z. A., Ong, S. A., Wong, Y. S., Azhari, A. W., & Ozir, S. N. (2018). Lignin recovery and it effects quality of anaerobic treated palm oil mill effluent (ATPOME). *E3S Web of Conferences,* 34: 1-7.

Igwe, J. C., Onyegrado, C. O., & Abia, A. A. (2010). Adsorption isotherm studies of BOD, TSS and colour reduction from palm mill effluent (POME) using boiler fly ash. *ECLÉTICA química,* 35(3): 195-208.

Irvan. (2012). Effect of Ni and Co as trace metals on digestion performance and biogas produced from the fermentation of palm oil mill effluent. *International Journal of Waste Resources,* 2(2): 16-19.

Jagtoyen, M., Groppo, J., & Derbyshire, F. (1993). Activated carbons from bituminous coals by reaction with H_3PO_4: The influence of coal cleaning. *Fuel Processing Technology,* 34(2): 85-96.

Jalani, N. F., Aziz, A. A., Wahab, N. A., Hassan, W. H. W., & Zainal, N. H. (2016). Application of palm kernel shell activated carbon for the removal of pollutant and color in palm oil mill effluent treatment. *Journal of Earth, Environment and Health Sciences,* 2(1): 15-20.

Jamal, P., Idris, Z. M., & Alam, M. Z. (2011). Effects of physicochemical parameters on the production of phenolic acids from palm oil mill effluent under liquid-state fermentation by *Aspergillus niger* IBS-103ZA. *Food Chemistry,* 124(4): 1595-1602.

Jarusiripot, C. (2014). Removal of reactive dye by adsorption over chemical pretreatment coal based bottom ash. *Procedia Chemistry,* 9: 121-130.

Jayaranjan, M. L. D., Hullebusch, E. D. V., & Annachhatre, A. P. (2014). Reuse options for coal fired power plant bottom ash and fly ash. *Reviews in Environmental Science and Bio/Technology,* 13(4): 467-486.

Jiménez, V., Sánchez, P., & Romero, A. (2017). 2 - Materials for activated carbon fiber synthesis. In J. Y. Chen (Ed.), *Activated Carbon Fiber and Textiles* (pp. 21-38). Oxford: Woodhead Publisher.

Jin, H., Wang, X., Gu, Z., & Polin, J. (2013). Carbon materials from high ash biochar for supercapacitor and improvement of capacitance with HNO_3 surface oxidation. *Journal of Power Sources,* 236: 285-292.

Karakoyun, N., Kubilay, S., Aktas, N., Turhan, O., Kasimoglu, M., Yilmaz, S., & Sahiner, N. (2011). Hydrogel–biochar composites for effective organic contaminant removal from aqueous media. *Desalination,* 280(1): 319-325.

Karanac, M., Đolić, M., Veljović, Đ., Rajaković-Ognjanović, V., Veličković, Z., Pavićević, V., & Marinković, A. (2018). The removal of Zn^{2+}, Pb^{2+}, and As(V) ions by lime activated fly ash and valorization of the exhausted adsorbent. *Waste Management,* 78: 366-378.

Karri, R. R., Tanzifi, M., Tavakkoli Yaraki, M., & Sahu, J. N. (2018). Optimization and modeling of methyl orange adsorption onto polyaniline nano-adsorbent through response surface methodology and differential evolution embedded neural network. *Journal of Environmental Management,* 223: 517-529.

Kastner, J. R., Miller, J., & Das, K. C. (2009). Pyrolysis conditions and ozone oxidation effects on ammonia adsorption in biomass generated chars. *Journal of Hazardous Materials,* 164(2): 1420-1427.

Kaveeshwar, A. R., Kumar, P. S., Revellame, E. D., Gang, D. D., Zappi, M. E., & Subramaniam, R. (2018). Adsorption properties and mechanism of barium (II) and strontium (II) removal from fracking wastewater using pecan shell based activated carbon. *Journal of Cleaner Production,* 193: 1-13.

Keller, M. (2000). Tannin Removal. Retrieved 15 April 2017 from https://www.wqpmag.com/tannin-removal.

Kong, S. H., Loh, S. K., Bachmann, R. T., Rahim, S. A., & Salimon, J. (2014). Biochar from oil palm biomass: A review of its potential and challenges. *Renewable and Sustainable Energy Reviews,* 39: 729-739.

Kotz J. C. (2016). *Chemistry and Chemical Reactivity*. Content Technologies, Inc.

Kumar, T. H. V., Sivasankar, V., Fayoud, N., Oualid, H. A., & Sundramoorthy, A. K. (2018). Synthesis and characterization of coral-like hierarchical MgO incorporated fly ash composite for the effective adsorption of azo dye from aqueous solution. *Applied Surface Science,* 449: 719-728.

Kusmiyati, Listyanto, P. A., Vitasary, D., Indra, R., Islamica, D., & Hadiyanto, H. (2017). Coal bottom ash and activated carbon for removal of vertigo blue dye in batik textile wastewater: adsorbent characteristic, isotherms, and kinetics studies. *Walailak Journal of Science and Technology,* 14(5): 427-439.

Kwaghger, A., & Ibrahim, J. S. (2013). Optimization of conditions for the preparation of activated carbon from mango nuts using HCl. *American Journal of Engineering Research,* 2(7): 74-85.

Lahin, F. A., Sarbatly, R., & Suali, E. (2016). Polishing of POME by Chlorella sp. in suspended and immobilized system. *IOP Conference Series: Earth and Environmental Science,* 36: 1-10.

Lam, S. S., Liew, R. K., Wong, Y. M., Yek, P. N. Y., Ma, N. L., Lee, C. L., & Chase, H. A. (2017). Microwave-assisted pyrolysis with chemical activation, an innovative method to convert orange peel into activated carbon with improved properties as dye adsorbent. *Journal of Cleaner Production,* 162: 1376-1387.

Lamine, S. M., Ridha, C., Mahfoud, H.-M., Mouad, C., Lotfi, B., & Al-Dujaili, A. H. (2014). Chemical activation of an activated carbon prepared from coffee residue. *Energy Procedia,* 50: 393-400.

Lauwerys, R., & Lison, D. (1994). Health risks associated with cobalt exposure - an overview. *The Science of the Total Environment,* 150: 1-6

Lehman J., 2007. *A handful of carbon*. Nature 447, 143-144

Li, L., Sun, Z., Li, H., & Keener, T. C. (2012). Effects of activated carbon surface properties on the adsorption of volatile organic compounds. *Journal of the Air & Waste Management Association,* 62(10): 1196-1202.

Li, S., & Chen, G. (2018). Using hydrogel-biochar composites for enhanced cadmium removal from aqueous media. *Material Science & Engineering International Journal,* 2(6): 294-298.

Li, S., Cooke, R. A., Wang, L., Ma, F., & Bhattarai, R. (2017). Characterization of fly ash ceramic pellet for phosphorus removal. *Journal of Environmental Management,* 189: 67-74.

Liew W. L., Kassim M. A., Muda K. A., Loh S. K., & Affam A. C. (2015). Conventional methods and emerging wastewater polishing technologies for palm oil mill effluent treatment: A review. *Journal of Environmental Management,*149: 222-35.

Liew, R. K., Azwar, E., Yek, P. N. Y., Lim, X. Y., Cheng, C. K., Ng, J. H., Jusoh, A., Lam, W. H., Ibrahim, M. D., Ma, N. L., & Lam, S. S. (2018). Microwave pyrolysis with KOH/NaOH mixture activation: A new approach to produce micro-mesoporous activated carbon for textile dye adsorption. *Bioresource technology,* 266: 1-10.

Liu, Z., Xue, Y., Gao, F., Cheng, X., & Yang, K. (2016). Removal of ammonium from aqueous solutions using alkali-modified biochars. *Chemical Speciation & Bioavailability,* 28(1-4): 26–32.

Loh, S. K., Lai, M. E., Ngatiman, M., Lim, W. S., Choo, Y. M., Zhang, Z., & Salimon, J. (2013). Zero discharge treatment technology of palm oil mill effluent. *Journal of Oil Palm Research,* 25(3): 273-281.

Lou, K., Rajapaksha, A. U., Ok, Y. S., & Chang, S. X. (2016). Pyrolysis temperature and steam activation effects on sorption of phosphate on pine sawdust biochars in aqueous solutions. *Chemical Speciation & Bioavailability,* 28(1-4): 42-50.

Loy, A. C. M., Yusup, S., Lam, M. K., Chin, B. L. F., Shahbaz, M., Yamamoto, A., & Acda, M. N. (2018). The effect of industrial waste coal bottom ash as catalyst in catalytic pyrolysis of rice husk for syngas production. *Energy Conversion and Management,* 165: 541-554.

Lozano-Castelló, D., Lillo-Ródenas, M. A., Cazorla-Amorós, D., & Linares-Solano, A. (2001). Preparation of activated carbons from Spanish anthracite: I. Activation by KOH. *Carbon,* 39(5): 741-749.

Ma, A. N., Cheah, S. C., & Chow, M. C., (1993). Current status of palm oil processing wastes management. In: Yeoh, B.G., Chee, K.S., Phang, S.M., Isa, Z., Idris, A., Mohamed, M. (Eds.), Waste Management in Malaysia: Current Status and Prospects for Bioremediation. Ministry of Science, Technology and the Environment, Malaysia, pp. 111 - 136.

Madhavi, T. P., Srimurali, M., & Prasad, K. N. (2014). Color removal from industrial waste water using alum. *Journal of Environmental Research And Development,* 8(4): 890-894.

Markandeya, Shukla, S. P., & Mohan, D. (2017). Toxicity of disperse dyes and its removal from wastewater using various adsorbents: A Review. *Research Journal of Environmental Toxicology,* 11: 72-89.

Marto, A., & Tan, C. S. (2016). Properties of coal bottom ash from power plants in Malaysia and its suitability as geotechnical engineering material. *Jurnal Teknologi,* 78(8): 1-10.

Masel, R. I. (1996). *Principle of Adsorption and Reaction on Solid Surfaces*: John Wiley & Sons, INC.

Md Din, M.F., Ujang, Z., Muhd Yunus, S., & van Loosdrecht, M.C.M., (2006). Storage of polyhydroxyalkanoates (PHA) in fed-batch mixed culture using palm oil mill effluent (POME). Paper presented at 4th Seminar on Water Management (JSPS-VCC), Johor; pp. 119-127.

Meij, R., & te Winkel, H. (2007). The emissions of heavy metals and persistent organic pollutants from modern coal-fired power stations. *Atmospheric Environment,* 41(40): 9262-9272.

Merck. (2018). Analytical Method: Color, ADMI as per APHA 2120 F. Retrieved 3 March 2018 from https://www.sigmaaldrich.com/technical-documents/articles/analytical-applications/photometry/color-admi-as-per-apha-2120-f.html

Mittal, J., Jhare, D., Vardhan, H., & Mittal, A. (2013). Utilization of bottom ash as a low-cost sorbent for the removal and recovery of a toxic halogen containing dye eosin yellow. *Desalination and Water Treatment,* 52(22): 1-12.

Mohammed, R. R. (2013). Decolourization of biologically treated palm oil mill effluent (POME) using adsorption technique. *International Refereed Journal of Engineering and Science,* 2(10): 01-11.

Mohammed, R. R., & Chong, M. F. (2014). Treatment and decolorization of biologically treated palm oil mill effluent (POME) using banana peel as novel biosorbent. *Journal of Environmental Management,* 132: 237-249.

Mohammed, R. R., Ketabchi, 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.

Mohan, D., Kumar, S., & Srivastava, A. (2014). Fluoride removal from ground water using magnetic and nonmagnetic corn stover biochars. *Ecological Engineering,* 73: 798-808.

Mohan, D., Charles U. Pittman, J., & Steele, P. H. (2006). Pyrolysis of wood/biomass for bio-oil: a critical review. *Energy Fuels,* 20(3): 848–889.

Mohan, S. V., & Karthikeyan, J. (1997). Removal of lignin and tannin colour from aqueous solution by adsorption onto activated charcoal. *Environmental Pollution,* 97(1-2): 183-187.

Mokhtar, M. M., Taib, R. M., & Hassim, M. H. (2014). Understanding selected trace elements behavior in a coal-fired power plant in Malaysia for assessment of abatement technologies. *Journal of the Air & Waste Management Association,* 64(8): 867-878.

Mondal, M. K., Mishra, G., & Dasgupta, B. (2009). *Agricultural Waste as Low Cost Adsorbent for Heavy Metal Removal - A review Separation Process*. New Delhi

Muhardi, Marto, A., Kassim, K. A., Maktar, A. M., Lee, F. W., & Yap, S. L. (2010). Engineering characteristics of Tanjung Bin coal ash. *Electronic Journal of Geotechnical Engineering,* 15: 1117-1129.

Mustapha, A. (2015). Colour removal technology using ozone in textile industrial wastewater effluent: an overview. *International Journal of Innovative Scientific & Engineering,* 3(2): 45-51.

Naganathan, S., Subramaniam, N., & Mustapha, K. N. (2012). Development of brick using thermal power plant bottom ash and fly ash. *Asian Journal of Civil Engineering (Building and Housing),* 13(1): 275-287.

Neoh, C. H., Yahya, A., Adnan, R., Majid, Z. A., & Ibrahim, Z. (2013). Optimization of decolourization of palm oil mill effluent (POME) by growing cultures of *Aspergillus fumigatus* using response surface methodology. *Environmental Science and Pollution Research,* 20: 2912-2923.

Neoh, C. H., Lam, C. Y., Lim, C. K., Yahya, A., & Ibrahim, Z. (2014). Decolorization of palm oil mill effluent using growing cultures of *Curvularia clavata*. *Environmental Science and Pollution Research,* 21(6): 4397-4408.

Nidheesh, P. V., Gandhimathi, R., Ramesh, S. T., & Singh, T. S. A. (2012). Kinetic analysis of crystal violet adsorption on to bottom ash. *Turkish Jounal of Engineering and Environmental Sciences,* 36: 249 – 262.

Oliveira, G., Calisto, V., Santos, S. M., Otero, M., & Esteves, V. I. (2018). Paper pulp-based adsorbents for the removal of pharmaceuticals from wastewater: A novel approach towards diversification. *Science of The Total Environment,* 631-632: 1018-1028.

Owoeye, S. S., Oji, B., & Aderiye, J. (2015). Effect of temperature, time and atmospheric condition on active silica extraction from corn cob ash. *IJETI International Journal of Engineering & Technology Innovations,* 2(3): 1-5.

Pengthamkeerati, P., Satapanajaru, T., Chatsatapattayakul, N., Chairattanamanokorn, P., & Sananwai, N. (2010). Alkaline treatment of biomass fly ash for reactive dye removal from aqueous solution. *Desalinaion,* 261(1-2): 34-40.

Perlman, H. (2016). Water Colour. Retrieved 20 April 2018 from http://water.usgs.gov/edu/color.html

Petriciolet, A. B., Castillo, D. I. M., & Reynel Ávila, H. E. (2017). *Adsorption Processes for Water Treatment and Purification*. Switzerland: Springer.

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

Poh, P. E., Yong, W.-J., & Chong, M. F. (2010). Palm oil mill effluent (POME) characteristic in high crop season and the applicability of high-rate anaerobic bioreactors for the treatment of POME. *Industrial & Engineering Chemistry Research,* 49: 11732-11740.

Popuri, A. K., Mandapati, R. N., Pagala, B., & Guttikonda, P. (2016). Color removal from dye wastewater using adsorption. *International Journal of Pharmaceutical Sciences Review and Research,* 39(1): 115-118.

Rahman, A. A., Sulaiman, F., & Abdullah, N. (2016). Influence of washing medium pre-treatment on pyrolysis yields and product characteristics of palm kernel shell. *Journal of Physical Science,* 27(1): 53-75.

Rajkumar, R., & Takriff, M. S. (2015). Nutrient removal from anaerobically treated palm oil mill effluent by *Spirulinaplatensis* and *Scenedesmusdimorphus Scholars Research Library,* 7(7): 416-421.

Rajwar, B. S., & Pandey, I. K. (2015). removal of COD & BOD from contaminated water by using fly ash as an adsorbent: A Review. *International Journal of Logistics & Supply Chain Management Perspectives,* 4(1): 1537-1543.

Rakamthong, C., & Prasertsan, P. (2011). *Decolorization and phenol removal of anaerobic palm oil mill effluent by Phanerochaete chrysosporium ATCC 24725.* Paper presented at the TIChE International Conference 2011 Thailand.

Rashed, M. N. (2013). *Adsorption Technique for the Removal of Organic Pollutants from Water and Wastewater* (pp. 167-194): INTECH.

Rashidi, N. A., & Yusup, S. (2016). An overview on the potential of coal based bottom ash as low-cost adsorbents. *ACS Sustainable Chemistry & Engineering,* 4(4): 1870-1884.

Ratpukdi, T. (2012). Decolorization of anaerobically treated palm oil mill wastewater using combined coagulation and vacuum ultraviolet-hydrogen peroxide. *International Journal of Chemical Engineering and Applications,* 3(5): 333-336.

Reuters. (2018). Indonesia, Malaysia palm oil output to rise in 2018; may pressure prices. *Star Online*.

Roque-Malherbe, R. M. A. (2007). *Adsorption and Diffusion in Nanoporous Materials*: CRC Press.

Rouquerol, J., Sing, K. S. W., & Llewellyn, P. (2014). *Adsorption by Powders and Porous Solids (Second Edition)* (pp. 393-465). Oxford: Academic Press.

Rupani, P. F., Singh, R. P., Ibrahim, M. H., & Esa, N. (2010). Review of current palm oil mill effluent (POME) treatment methods: vermicomposting as a sustainable practice. *World Applied Sciences Journal,* 11(1): 70-81.

Sadaka, S., Sharara, M., Ashworth, A., Keyser, P., Allen, F., & Wright, A. (2014). Characterization of biochar from switchgrass carbonization. *Energies,* 7(2): 548-567.

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.

Said, M., Mohammad, A. W., Nor, M. T. M., Abdullah, S. R. S., & Hasan, H. A. (2015). Investigation of three pre-treatment methods prior to nanofiltration membrane for palm oil mill treatment. *Sains Malaysiana,* 44(3): 421-427.

Said, M., Hasan, H. A., Nor, M. T. M., & Mohammad, A. W. (2016). Removal of COD, TSS and colour from palm oil mill effluent (POME) using montmorillonite. *Desalination and Water Treatment,* 57: 10490–10497.

Saleh, S. M., Maarof, H. I., Rahim, S. N. S. A., & Nasuha, N. (2012). Adsorption of congo red onto bottom ash. *Journal of Applied Science,* 12(11): 1181-1185.

Sanyang, L., Ghani, W. A. W. A., Idris, A., & Ahmad, M. B. (2014). Zinc removal from wastewater using hydrogel modified biochar. *Applied Mechanics and Materials,* 625: 842-846.

Saud, P. S., Pant, B., Park, M., Chae, S. H., Park, S. J., Ei-Newehy, M., Al-Deyab, S. S., & Kim, H. Y. (2015). Preparation and photocatalytic activity of fly ash incorporated TiO_2 nanofibers for effective removal of organic pollutants. *Ceramics International,* 41(1): 1771-1777.

Sayğılı, H., & Güzel, F. (2016). High surface area mesoporous activated carbon from tomato processing solid waste by zinc chloride activation: process optimization, characterization and dyes adsorption. *Journal of Cleaner Production,* 113: 995-1004.

Selvakumar, S., Manivasagan, R., & Chinnappan, K. (2013). Biodegradation and decolourization of textile dye wastewater using *Ganoderma lucidum*. *3 Biotech,* 3(1): 71-79.

Shahbaz, M., Yusup, S., Inayat, A., Patrick, D. O., & Pratama, A. (2016). Application of response surface methodology to investigate the effect of different variables on conversion of palm kernel shell in steam gasification using coal bottom ash. *Applied Energy,* 184: 1306-1315.

Shen, Y., & Fu, Y. (2018). KOH-activated rice husk char via CO_2 pyrolysis for phenol adsorption. *Materials Today Energy,* 9: 397-405.

Sia, Y. Y., Tan, I. A. W., & Abdullah, M. O. (2017). Adsorption of colour, TSS and COD from palm oil mill effluent (POME) using acid-washed coconut shell activated carbon: Kinetic and mechanism studies. *MATEC Web of Conferences,* 87: 1-7.

Siddiquee, S., Shafawati, S. N., & Naher, L. (2017). Effective composting of empty fruit bunches using potential *Trichoderma* strains. *Biotechnology Reports,* 13: 1-7.

Sing, K. S. W. (2014). 10 - Adsorption by Active Carbons. In F. Rouquerol, J. Rouquerol, K. S. W. Sing, P. Llewellyn, & G. Maurin (Eds.), *Adsorption by Powders and Porous Solids* (pp. 321-391). Oxford: Academic Press.

Soares Maia, D. A., Alexandre de Oliveira, J. C., Nazzarro, M. S., Sapag, K. M., López, R. H., Lucena, S. M. P. d., & de Azevedo, D. C. S. (2018). CO_2 gas-adsorption calorimetry applied to the study of chemically activated carbons. *Chemical Engineering Research and Design,* 136: 753-760.

Sricharoenchaikul, V., Pechyen, C., Aht-ong, D., & Atong, D. (2008). Preparation and characterization of activated carbon from the pyrolysis of physic nut (Jatropha curcas L.) waste. *Energy & Fuels,* 22(1): 31-37.

Subramaniam, M. N., Goh, P. S., Lau, W. J., Tan, Y. H., Ng, B. C., & Ismail, A. F. (2017). Hydrophilic hollow fiber PVDF ultrafiltration membrane incorporated with titanate nanotubes for decolourization of aerobically-treated palm oil mill effluent. *Chemical Engineering Journal,* 316: 101-110.

Sun, H., Hockaday, W. C., Masiello, C. A., & Zygourakis, K. (2012). Multiple control on the chemical and physical structure of biochars. *Industrial and Engineering Chemistry Research,* 51: 3587-3597.

Swaine, D.J. 1990. *Trace Elements in Coal*. London, UK: Butterworth.

Tabassum, S., Zhang, Y., & Zhang, Z. (2015). An integrated method for palm oil mill effluent (POME) treatment for achieving zero liquid discharge – A pilot study. *Journal of Cleaner Production,* 95: 148-155.

Takaya, C. A., Fletcher, L. A., Singh, S., Okwuosa, U. C., & Ross, A. B. (2016). Recovery of phosphate with chemically modified biochars. *Journal of Environmental Chemical Engineering,* 4: 1156–1165.

Tan, Y. H., Goh, P. S., Lai, G. S., Lau, W. J., & Ismail, A. F. (2014). Treatment of aerobic treated palm oil mill effluent (AT-POME) by using TiO_2 photocatalytic process. *Jurnal Teknologi,* 70(2): 61-63.

Tan, X., Liu, Y., Zeng, G., Wang, X., Hu, X., Gu, Y., & Yang, Z. (2015). Application of biochar for the removal of pollutants from aqueous solutions. *Chemosphere,* 125: 70-85.

Tan, Y. H., Goh, P. S., Ismail, A. F., Ng, B. C., & Lai, G. S. (2017). Decolourization of aerobically treated palm oil mill effluent (AT-POME) using polyvinylidene fluoride (PVDF) ultrafiltration membrane incorporated with coupled zinc-iron oxide nanoparticles. *Chemical Engineering Journal,* 308: 359-369.

Teka, T., & Enyew, S. (2014). Study on effect of different parameters on adsorption efficiency of low cost activated orange peels for the removal of methylene blue dye. *International Journal of Innovation and Scientific Research,* 8(1): 106-111.

Ugoji, E. O. (1997). Anaerobic digestion of palm oil mill effluent and its utilization as fertilizer for environmental protection. *Renewable Energy,* 10(2): 291-294.

Ugurlu, M., Gurses, A., Yalcin, M., & Dogar, C. (2005). Removal of phenolic and lignin compounds from bleached kraft mill effluent by fly ash and sepiolite. *Adsorption,* 11: 87-97.

Varqa, S. (2017). Essential Palm Oil Statistics. Retrieved 10 June 2018 from http://www.palmoilanalytics.com/files/epos-final-59.pdf

Vejahati, F., Xu, Z., & Gupta, R. (2010). Trace elements in coal: Associations with coal and minerals and their behavior during coal utilization – A review. *Fuel,* 89(4): 904-911.

Vimonses, V., Lei, S., Jin, B., Chow, C. W. K., & Saint, C. (2009). Kinetic study and equilibrium isotherm analysis of congo red adsorption by clay materials. *Chemical Engineering Journal,* 148: 354-364.

Visa, M. (2012). Tailoring fly ash activated with bentonite as adsorbent for complex wastewater treatment. *Applied Surface Science,* 263: 753-762.

Wang, C., & Wang, H. (2018). Pb(II) sorption from aqueous solution by novel biochar loaded with nano-particles. *Chemosphere,* 192: 1-4.

Wang, L. K., Tay, J. H., Tay, S. T. L., & Hung, Y. T. (2010). *Environmental Bioengineering* (Vol. 11). New York, London: Humana Press.

Wang, S., & Luo, Z. (2017). Lignin *Pyrolysis of biomass* (Vol. 1). Berlin: Walter de Gruyter.

Wang, S., & Peng, Y. (2010). Natural zeolites as effective adsorbents in water and wastewater treatment. *Chemical Engineering Journal,* 156(1): 11-24.

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

Wang, S., Gao, B., Zimmerman, A. R., Li, Y., Ma, L., Harris, W. G., & Migliaccio, K. W. (2015). Physicochemical and sorptive properties of biochars derived from woody and herbaceous biomass. *Chemosphere,* 134: 257-262.

Wawrzkiewicz, M., Wiśniewska, M., & Gun'ko, V. M. (2017). Application of silica–alumina oxides of different compositions for removal of C.I. Reactive Black 5 dye from wastewaters. *Adsorption Science & Technology,* 35(5): 448-457.

Wilson, K. (2016). How citizen science is transforming river management in Malaysian Borneo. Retrieved 20 April 2018 from https://news.mongabay.com/wildtech/2016/11/how-citizen-science-is-transforming-river-management-in-borneo/

Wu, F. C., Wu, P. H., Tseng, R. L., & Juang, R. S. (2010a). Preparation of activated carbons from unburnt coal in bottom ash with KOH activation for liquid-phase adsorption. *Journal of Environmental Management,* 91(5): 1097-1102.

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

Xia, M., Ye, C., Pi, K., Liu, D., & Gerson, A. R. (2018). Cr(III) removal from simulated solution using hydrous magnesium oxide coated fly ash: Optimization by response surface methodology (RSM). *Chinese Journal of Chemical Engineering,* 26(5): 1192-1199.

Xu, G., & Shi, X. (2018). Characteristics and applications of fly ash as a sustainable construction material: A state-of-the-art review. *Resources, Conservation and Recycling,* 136: 95-109.

Xue, Y., Gao, B., Yao, Y., Inyang, M., Zhang, M., Zimmerman, A. R., & Ro, K. S. (2012). Hydrogen peroxide modification enhances the ability of biochar (hydrochar) produced from hydrothermal carbonization of peanut hull to remove aqueous heavy metals: Batch and column tests. *Chemical Engineering Journal,* 200-202: 673-680.

Yahya, A. A., Ali, N., Kamal, N. L. M., Shahidan, S., Beddu, S., Nuruddin, M. F., & Shafiq, N. (2017). Reducing Heavy Metal Element from Coal Bottom Ash by Using Citric Acid Leaching Treatment. *MATEC Web of Conferences,* 103: 1-7.

Yildirim, N. C., Tanyol, M., Yildirim, N., Serdar, O., & Tatar, S. (2018). Biochemical responses of *Gammarus pulex* to malachite green solutions decolorized by *Coriolus versicolor* as a biosorbent under batch adsorption conditions optimized with response surface methodology. *Ecotoxicology and Environmental Safety,* 156: 41-47.

Zahrim, A. Y., Nasimah, A., & Hilal, N. (2014). Pollutants analysis during conventional palm oil mill effluent (POME) ponding system and decolourisation of anaerobically treated POME via calcium lactate-polyacrylamide. *Journal of Water Process Engineering,* 4: 159-165.

Zahrim, A. Y., Rachel, F. M., Menaka, S., Su, S. Y., Melvin, F., & Chan, E. S. (2009). Decolourisation of anaerobic palm oil mill effluent via activated sludge-granular activated carbon. *World Applied Sciences Journal,* 5: 126-129.

Zhang, H. Y., Zheng, Y., Hu, H. T., & Qi, J. Y. (2011). Use of municipal solid waste incineration bottom ash in adsorption of heavy metals. *Key Engineering Materials,* 474-476: 1099-1102.

Zhang, Y. J., Kang, L., & Liu, L. C. (2015). 27 - Alkali-activated cements for photocatalytic degradation of organic dyes *Handbook of Alkali-Activated Cements, Mortars and Concretes* (pp. 729-775). Oxford: Woodhead Publisher.

Zielińska, M., & Galik, M. (2017). Use of ceramic membranes in a membrane filtration supported by coagulation for the treatment of dairy wastewater. *Water, Air, & Soil Pollution,* 228(173): 1-12.

Zinatizadeh, A. A. L., Pirsaheb, M., Bonakdari, H., & Younesi, H. (2010). Response surface analysis of effects of hydraulic retention time and influent feed concentration on performance of an UASFF bioreactor. *Waste Management,* 30(10): 1798-1807.

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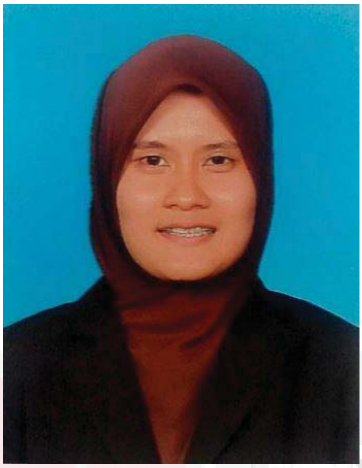

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LIST OF PUBLICATION

A. Published

Saleh, S., Kamarudin, K. B., Ghani, W. A. W. A. K., & Kheang, L. S. (2016). Removal of organic contaminant from aqueous solution using magnetic biochar. *Procedia Engineering,* 148: 228 – 235.

B. Accepted

Saleh, S., Ghani, W. A. W. A. K., & Kheang, L. S. (2019). Treated coal bottom ash for palm oil mill effluent (POME) decolourization. *Journal of Physical Science,* 30(3).

Saleh, S., Ghani, W. A. W. A. K., & Kheang, L. S. (2019). Decolourization of palm oil mill effluent (POME) treatment technologies: a review. *Journal of Oil Palm Research.*

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