REMOVAL OF MERCURY (II) ION FROM INDUSTRIAL WASTEWATER USING PALM OIL FUEL ASH

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Master of Science

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 Master of Science in Chemical Engineering.

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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.

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TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

C_o	Initial concentration
C_e	Residual concentration
K_C	Equilibrium constant
K_F	Indication of the adsorption
K_L	Langmuir constant
k_1	Equilibrium rate constant of pseudo first-order adsorption
k_2	Rate constant of second-order adsorption
m	Mass
1/n	Adsorption intensity
q_e	Adsorption capacity at the time of equilibrium
q_t	Adsorption capacity at time
q_m	Maximum adsorption capacity
R^2	Correlation coefficient
R_L	Value of separation factor
R	Percent removal
t	Time
T	Temperature
V	Volume
$\Delta G°$	Gibbs free energy
$\Delta H°$	Enthalpy
$\Delta S°$	Entropy

LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
AMD	Acid mine drainage
BET	Brunauer-Emmett-Teller
BOD	Biochemical oxygen demand
CCD	Central composite design
COD	Chemical oxygen demand
DOE	Design of experiment
EFB	Empty fruit bunches
FFD	Fractional factorial design
FTIR	Fourier transform infrared spectrometry
G-POFA	Ground-Palm oil fuel ash
OFAT	One factor at a time
OPC	Ordinary Portland cement
POS	Palm oil shell
POFA	Palm oil fuel ash
RSM	Response surface methodology
SEM	Scanning electron microscopy
TGA	Thermal gravimetric analysis
TSS	Total suspended solid
WHO	World Health Organization

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ABSTRAK

Abu bahan api kelapa sawit (POFA) yang diubah suai telah digunakan sebagai penjerap untuk menyingkirkan merkuri (II) ion dari air sisa industri. Keputusan awal eksperimen menunjukkan bahawa POFA mempunyai keupayaan penjerapan yang baik untuk ion merkuri (II). Proses penjerapan ion merkuri (II) menggunakan POFA bukan sahaja menyumbang kepada penjerapan merkuri dari air sisa industri tetapi juga dapat mengurangkan pencemaran alam sekitar disebabkan oleh pengumpulan dan pertambahan sisa buangan tersebut. Oleh itu, POFA telah diperkenalkan sebagai bahan mentah dalam kajian ini untuk memaksimumkan penggunaan sisa buangan dari kelapa sawit. POFA telah diubahsuai secara pengaktifan kimia menggunakan asid sulfurik. Manakala, pengimbas mikroskop elektron (SEM), transformasi empatier spektrometri inframerah (FTIR), analisis gravimetrik haba (TGA), dan analisis kawasan permukaan Brunauer-Emmett-Teller (BET) telah digunakan untuk melihat struktur POFA sebelum dan selepas pengubahsuaian berlaku. Kajian saringan dianalisis menggunakan reka bentuk faktorial fraksional (FFD). Dalam kajian analisis faktorial, keadaan terbaik penyingkiran ion merkuri (II) ialah pada 98.03 ± 0.06 % apabila dilakukan pada kelajuan 100 rpm, pH 2, 5 mg/L kepekatan awal merkuri (II) ion, 0.25 g dos penjerap dan masa selama 4 jam. Dari kajian skrining ini, dua faktor iaitu masa kenalan dan kelajuan agitasi dipilih untuk analisis lanjut dalam bahagian pengoptimuman. Pengoptimuman kecekapan penyingkiran ion merkuri (II) telah dilakukan dengan menggunakan reka bentuk komposit pusat (CCD) dalam kaedah permukaan respon (RSM). Dalam reka bentuk komposit pusat (CCD), keadaan optimum bagi penyingkiran ion merkuri (II) telah diperolehi pada 150 rpm selama 5 jam ialah 98.93 % ± 0.02 % ion merkuri (II). Data keseimbangan pada pelbagai kepekatan dianalisis dengan model isoterma Langmuir dan Freundlich. Dari kajian ini, nilai pekali korelasi (R2) diperolehi daripada isoterma Freundlich ialah 0.9899. Kajian kinetik telah dijalankan dengan perintah pseudo pertama dan pseudo kedua persamaan tindak balas. Hasil mendapati bahawa proses pengambilan ion merkuri (II) mengikuti pseudo kedua persamaan tindak balas. Parameter termodinamik iaitu tenaga bebas Gibbs (ΔG °), entalpi (ΔH °) dan entropi (ΔS °) juga telah ditentukan. Hasil keputusan menunjukkan perubahan negatif pada tenaga bebas Gibbs (-764.32 kJ / mol) dan perubahan positif bagi entalpi (75531.86 kJ/mol). Ini menunjukkan bahawa penjerapan adalah proses spontan dan bersifat endotermik. POFA yang diubahsuai adalah penyerap yang baik untuk penghapusan ion merkuri (II) dengan penyingkiran merkuri 91.18 % daripada air sisa industri. Keputusan ini adalah setanding dengan penyelidik lain dalam lingkungan 90 hingga 95% penyingkiran ion merkuri (II). Secara keseluruhan, POFA mempunyai potensi untuk digunakan sebagai penjerap bagi menyingkirkan ion merkuri (II) dari air sisa industri disebabkan oleh prestasi yang tinggi dan ketersediaannya pada kos yang rendah.

ABSTRACT

Activated palm oil fuel ashes (POFA) were used as the adsorbents for the removal of mercury (II) ion from industrial wastewater. From the preliminary experimental results, it shows that the POFA had good adsorption capability for mercury (II) ion. The adsorption process of mercury (II) ion using POFA not only contributes to the mercury adsorption from industrial wastewater but also removes the environmental pollution caused by accumulation and abundance of waste in nature. Therefore, POFA was introduced as a raw material in this study to maximize the utilization of oil palm waste. POFA was activated using chemical activation and sulphuric acid used as a solvent before proceeding with mercury (II) ion adsorption process. Scanning electron microscopy (SEM), fourier transform infrared spectrometry (FTIR), thermal gravimetric analysis (TGA), and Brunauer-Emmett-Teller (BET) surface area analysis had been applied to observe the effect of the POFA structure before and after activation. The screening study was analyzed using fractional factorial design (FFD). In factorial analysis study, the best mercury (II) ion removal condition removed 98.03 ± 0.06 % when performed at 100 rpm of agitation speed, pH 2, 5 mg/L of initial mercury (II) ion concentration, 0.25 g of adsorbent dosages and 4 h of contact time. From this screening study, two factors which are contact time and agitation speed were selected for further analysis in optimization part. The optimization of mercury (II) ion removal efficiency was done by using central composite design (CCD) in response surface methodology (RSM). In central composite design (CCD), the optimum condition for mercury (II) ion removal was obtained at 150 rpm for 5 h which removed 98.93 ± 0.02 % of mercury (II) ion. The equilibrium data at various concentrations were analysed by Langmuir and Freundlich isotherms models. From this present study, the values of correlation coefficient (R2) obtained from the Freundlich isotherm was 0.9899. A kinetic study was carried out with pseudo first order and pseudo second order reaction equations. It was found that the mercury (II) ion uptake process followed the pseudo second order rate expression. Thermodynamic parameters of the Gibbs free energy ($\Delta G°$), enthalpy ($\Delta H°$), and entropy ($\Delta S°$) were also determined. The negative Gibbs free energy change (-764.32 kJ/mol) and the positive enthalpy change (75531.86 kJ/mol) indicated that adsorption was spontaneous process and endothermic nature. It was found that activated POFA was a good adsorbent for mercury (II) ion removal with 91.18 % mercury removal from industrial wastewater. This result was comparable to other researcher in the range from 90 to 95 % mercury (II) ion removal. Overall, POFA has the potential to be used as an adsorbent for the removal of mercury (II) ion from industrial wastewater due to its high performance and availability at low cost.

REFERENCES

Abdel-Raouf, M. S., and Abdul-Raheim, A. R. M. 2016. Removal of Heavy Metals from Industrial Waste Water by Biomass-Based Materials: A Review. *Journal of Pollution Effects & Control*, **05**(01): 1–13.

Abdul Awal, A. S. M., and Warid Hussin, M. 2011. Effect of Palm Oil Fuel Ash in Controlling Heat of Hydration of Concrete. *Procedia Engineering*, **14**: 2650–2657.

Achmad, A., Kassim, J., Suan, T. K., Amat, R. C., and Seey, T. L. 2012. Equilibrium, Kinetic and Thermodynamic Studies on The Adsorption of Direct Dye onto a Novel Green Adsorbent Developed from Uncaria Gambir Extract. *Journal of Physical Science*, **23**(1): 1–13.

Acquah, C., Sie Yon, L., Tuah, Z., Ling Ngee, N., and Danquah, M. K. 2016. Synthesis and Performance Analysis of Oil Palm Ash (OPA) Based Adsorbent as a Palm Oil Bleaching Material. *Journal of Cleaner Production*, **139**: 1098–1104.

Ahmad, A. A., Hameed, B. H., and Aziz, N. 2007. Adsorption of Direct Dye on Palm Ash: Kinetic and Equilibrium Modeling. *Journal of Hazardous Materials*, **141**(1): 70–76.

Ahmedna, M., Marshall, W. E., and Rao, R. M. 2000. Production of Granular Activated Carbons from Select Agricultural by-Products and Evaluation of Their Physical, Chemical and Adsorption Properties. *Bioresource Technology*, **71**(2): 113–123.

Aksoy, D. O., and Sagol, E. 2016. Application f Central Composite Design Method to Coal Flotation: Modelling, Optimization and Verification. *Fuel*, **183**: 609–616.

AL-Aoh, H. A., Maah, M. J., A.A.Ahmad, and Abas, M. R. 2012. Isotherm and Kinetic Studies of 4- Nitrophenol Adsorption by Naoh-Modified Palm Oil Fuel Ash. *Journal of Purity, Utility Reaction and Environment*, **1**(2): 104–120.

Al-aoh, H. A., Maah, M. J., Ahmad, A. A., and Abas, M. R. Bin. 2013. Adsorption of 4-Nitrophenol on Palm Oil Fuel Ash Activated by Amino Silane Coupling Agent Coupling Agent. *Desalination and Water Treatment*, **40**(February 2013): 37–41.

Al Bakri, A. M. M., Kamarudin, H., Bnhussain, M., Nizar, I. K., Rafiza, A. R., and Zarina, Y. 2012. The Processing, Characterization, and Properties of Fly Ash Based Geopolymer Concrete. *Rev. Adv. Mater. Sci*, **30**: 90–97.

Alothman, Z. A. 2012. A review: Fundamental Aspects of Silicate Mesoporous Materials. *Materials*, **5**(12): 2874–2902.

Alsubari, B., Shafigh, P., Ibrahim, Z., Alnahhal, M. F., and Jumaat, M. Z. 2018. Properties of Eco-Friendly Self-Compacting Concrete Containing Modified Treated Palm Oil Fuel Ash. *Construction and Building Materials*, **158**: 742–754.

Amad, T., Rafatullah, M., Ghazali, A., Sulaiman, O., and Hashim, R. 2011. Oil Palm Biomass–Based Adsorbents for the Removal of Water Pollutants—A Review. *Journal of Environmental Science and Health, Part C*, **29**(3): 177–222.

Anbia, M., and Amirmahmoodi, S. 2016. Removal of Hg (II) and Mn (II) From Aqueous Solution using Nanoporous Carbon Impregnated with Surfactants. *Arabian Journal of Chemistry*, **9**: 319–325.

Anirudhan, T. S., Divya, L., and Ramachandran, M. 2008. Mercury(II) Removal from Aqueous Solutions and Wastewaters Using a Novel Cation Exchanger Derived from Coconut Coir Pith And Its Recovery. *Journal of Hazardous Materials*, **157**(2): 620–627.

Ansari, M. H., Deshkar, A. M., Kelkar, P. S., Dharmadhikari, D. M., Hasan, M. Z., and Paramasivam, R. 1999. Mercury Removal from Wastewater by Steamed Hoof Powder. *Water Science and Technology*, **40**(7): 109–116.

Anwar Parvez, M., Al-Abdul Wahhab, H. I., Shawabkeh, R. A., and Hussein, I. A. 2014. Asphalt Modification using Acid Treated Waste Oil Fly Ash. *Construction and Building Materials*, **70**: 201–209.

Aravind, J., Lenin, C., Nancyflavia, C., Rashika, P., and Saravanan, S. 2015. Response Surface Methodology Optimization of Nickel (II) Removal using Pigeon Pea Pod Biosorbent. *International Journal of Environmental Science and Technology*, **12**(1): 105–114.

Arshadi, M., Amiri, M. J., and Mousavi, S. 2014. Kinetic, Equilibrium and Thermodynamic Investigations of Ni(II), Cd(II), Cu(II) and Co(II) Adsorption on Barley Straw Ash. *Water Resources and Industry*, **6**: 1–17.

Attari, M. 2015. *Mercury Removal from Aqueous Solution Using Natural , Synthetic , and Modified Zeolites*. The University of Western Ontario.

Attari, M., Bukhari, S. S., Kazemian, H., and Rohani, S. 2017. A Low-Cost Adsorbent from Coal Fly Ash for Mercury Removal from Industrial Wastewater. *Journal of Environmental Chemical Engineering*, **5**(1): 391–399.

Awal, A. S. . A., and Abubakar, S. I. 2011. Properties of Concrete Containing High Volume Palm Oil Fuel Ash: A Short- Term Investigation. *Malaysian Journal of Civil Engineering*, **23**(2): 54–66.

Awal, A. S. M. A., and Mohammadhosseini, H. 2016. Green Concrete Production Incorporating Waste Carpet Fiber and Palm Oil Fuel Ash. *Journal of Cleaner Production*, **137**: 157–166.

Awual, R., Hasan, M., Eldesoky, G. E., Khaleque, A., Rahman, M. M., and Naushad, M. 2016. Facile Mercury Detection and Removal From Aqueous Media Involving Ligand Impregnated Conjugate Nanomaterials. *Chemical Engineering Journal*, **290**: 243–251.

Ayd, H., and Baysal, G. 2006. Adsorption of Acid Dyes in Aqueous Solutions by Shells of Bittim (Pistacia Khinjuk Stocks), **196**: 248–259.

Bakri, Y., Mekaeel, A., and Koreih, A. 2011. Influence of Agitation Speeds and Aeration Rates on the Xylanase Activity of Aspergillus niger SS7. *Brazilian Archives of Biology and Technology*, **54**(4): 659–664.

Bao, S., Li, K., Ning, P., Peng, J., Jin, X., and Tang, L. 2017. Highly Effective Removal Of Mercury And Lead Ions From Wastewater By Mercaptoamine-Functionalised Silica-Coated Magnetic Nano-Adsorbents. *Applied Surface Science*, **393**: 457-466.

Bayramoğlu, G., and Arica, M. Y. 2007. Kinetics of Mercury Ions Removal from Synthetic Aqueous Solutions using by Novel Magnetic p(GMA-MMA-EGDMA) Beads. *Journal of Hazardous Materials*, **144**(1–2): 449–457.

Bello, O. S., Adegoke, K. A., and Akinyunni, O. O. 2017. Preparation and Characterization of a Novel Adsorbent from Moringa Oleifera Leaf. *Applied Water Science*, **7**(3): 1295–1305.

Benefield, L., and Morgan, J. 1990. Chemical precipitation. In *Water Quality and Treatment* (Vol. 3, pp. 141–197).

Bose-O'Reilly, S., McCarty, K. M., Steckling, N., and Lettmeier, B. 2010. *Current Problems in Pediatric and Adolescent Health Care*, **40**(8): 186–215.

Brunauer, S., Emmett, P. H., and Teller, E. 1938. Adsorption of Gases in Multimolecular Layers. *Journal of the American Chemical Society*, **60**(2): 309–319.

Chatterjee, S., Dutta, S., Mukherjee, M., Ray, P., and Basu, S. 2015. Studies on Removal of Lead(II) by Alginate Immobilized Bromelain (AIB). *Desalination and Water Treatment*, **56**(2): 409–424.

Chen, L., Ma, Y., Guo, Y., Zhang, C., Liang, Z., and Zhang, X. 2017. Quantifying The Effects of Operational Parameters on The Counting Efficiency of a Condensation Particle Counter using Response Surface Design of Experiments (DoE). *Journal of Aerosol Science*, **106**: 11–23.

Chmielniak, T., Słowik, K., and Sajdak, M. 2017. Mercury Removal by Mild Thermal Treatment of Coal. *Fuel*, **195**: 290–298.

Chowdhury, Z. Z. 2013. Preparation, Characterization and Adsorption Studies of Heavy Metals onto Activated Adsorbent Materials Derived from Agricultural Residues, 23–24.

Cobzaru, C., and Inglezakis, V. 2015. Ion Exchange. In *Progress in Filtration and Separation* (pp. 425–498). Elsevier.

Costa, F. do N., Korn, M. G. A., Brito, G. B., Ferlin, S., and Fostier, A. H. 2016. Preliminary Results of Mercury Levels in Raw and Cooked Seafood and Their Public Health Impact. *Food Chemistry*, **192**: 837–841.

Daffalla, S. B., Mukhtar, H., and Haharun, M. S. 2010. Characterization of Adsorbent Developed from Rice Husk : Effect of Surface Functional Group on Phenol Adsorption. *Journal of Applied Sciences*, **10**(12): 1060–1067.

Dashtian, K., and Zare-Dorabei, R. 2017. Synthesis and Characterization of Functionalized Mesoprous SBA-15 Decorated With Fe3O4 Nanoparticles for Removal of Ce(III) Ions from Aqueous Solution: ICP–OES Detection and Central Composite Design Optimization. *Journal of Colloid and Interface Science*, **494**: 114–123.

Dastkhoon, M., Ghaedi, M., Asfaram, A., Ahmadi Azqhandi, M. H., and Purkait, M. K. 2017. Simultaneous Removal of Dyes onto Nanowires Adsorbent Use of Ultrasound Assisted Adsorption to Clean Waste Water: Chemometrics for Modeling and Optimization, Multicomponent Adsorption and Kinetic Study. *Chemical Engineering Research and Design*, **124**: 222–237.

Davodi, B., Ghorbani, M., and Jahangiri, M. 2017. Adsorption of Mercury from Aqueous Solution on Synthetic Polydopamine Nanocomposite Based on Magnetic Nanoparticles using Box–Behnken Design. *Journal of the Taiwan Institute of Chemical Engineers*, **80**: 363–378.

Dawlet, A., Talip, D., Mi, H. Y., and Malikezhati. 2013. Removal of Mercury from Aqueous Solution using Sheep Bone Charcoal. *Procedia Environmental Sciences*, **18**: 800–808.

Department of Environment. 2009. Environmental Quality (Industrial Effluent) Regulations 2009. *Environmental Quality Act 1974*.

Ding, Y., Wang, S., Li, J., and Chen, L. 2016. Nanomaterial-Based Optical Sensors for Mercury Ions. *TrAC Trends in Analytical Chemistry*, **82**: 175–190.

Dong, S., and Sartaj, M. 2016. Statistical Analysis and Optimization of Ammonia Removal from Landfill Leachate by Sequential Microwave/Aeration Process using Factorial Design and Response Surface Methodology. *Journal of Environmental Chemical Engineering*, **4**(1): 100–108.

Dos Santos, R. P., Martins, J., Gadelha, C., Cavada, B., Albertini, A. V., Arruda, F., … Freire, V. 2014. Coal Fly Ash Ceramics: Preparation, Characterization, and Use in The Hydrolysis of Sucrose. *The Scientific World Journal*, 1–7.

Eagles-Smith, C. A., Wiener, J. G., Eckley, C. S., Willacker, J. J., Evers, D. C., Marvin-DiPasquale, M., … Ackerman, J. T. 2016. Mercury in Western North America: A Synthesis of Environmental Contamination, Fluxes, Bioaccumulation, and Risk to Fish and Wildlife. *Science of The Total Environment*, **568**: 1213–1226.

Eckersley, N. 2010. *Advanced mercury removal technologies*. *Gulf Publishing Company*.

Elhami, S., and Shafizadeh, S. 2016. Removal of Mercury (II) using Modified Nanoclay. *Materials Today: Proceedings*, **3**(8): 2623–2627.

Esfandiyari, T., Nasirizadeh, N., Dehghani, M., and Ehrampoosh, M. H. 2017. Graphene Oxide Based Carbon Composite as Adsorbent for Hg Removal: Preparation, Characterization, Kinetics and Isotherm Studies. *Chinese Journal of Chemical Engineering*, **25**(9): 1170–1175.

Esmaeili, A., Saremnia, B., and Kalantari, M. 2015. Removal of Mercury(II) from Aqueous Solutions by Biosorption on the Biomass of Sargassum Glaucescens and Gracilaria Corticata. *Arabian Journal of Chemistry*, **8**(4): 506–511.

Fatimah, I., Sahroni, I., Purnama, H., Nugraha, M. R., and Ayil, U. 2015. Applied Clay Science Ceramic Membrane Based on TiO_2 -Modified Kaolinite as a Low Cost Material for Water Filtration, **118**: 207–211.

Fu, F., Xie, L., Tang, B., Wang, Q., and Jiang, S. 2012. Application of a Novel Strategy—Advanced Fenton-Chemical Precipitation to the Treatment of Strong Stability Chelated Heavy Metal Containing Wastewater. *Chemical Engineering Journal*, **189**: 283–287.

Garba, Z. N., Bello, I., Galadima, A., and Lawal, A. Y. 2016. Optimization of Adsorption Conditions using Central Composite Design for the Removal of Copper (II) and Lead (II) by Defatted Papaya Seed. *Karbala International Journal of Modern Science*, **2**(1): 20–28.

Geyikc, F. 2016. Factorial Design Analysis for Adsorption of Indigo acarmine onto Montmorillonite-Evaluation of the Kinetics and Equilibrium Data. *Progress in Organic Coatings*, 1–7.

Ghodbane, I., and Hamdaoui, O. 2008. Removal of Mercury(II) from Aqueous Media Using Eucalyptus Bark: Kinetic And Equilibrium Studies. *Journal of Hazardous Materials*, **160**(2–3): 301–309.

Hadi, P., To, M.-H., Hui, C.-W., Lin, C. S. K., and McKay, G. 2015. Aqueous Mercury Adsorption by Activated Carbons. *Water Research*, **73**: 37–55.

Hassan, A. F., and Hrdina, R. 2017. Chitosan/Nanohydroxyapatite Composite Based Scallop Shells as an Efficient Adsorbent for Mercuric Ions: Static and Dynamic Adsorption Studies. *International Journal of Biological Macromolecules*, 1–20.

Hassan, S. S. M., Awwad, N. S., and Aboterika, A. H. A. 2008. Removal of Mercury(II) from Wastewater using Camel Bone Charcoal. *Journal of Hazardous Materials*, **154**(1–3): 992–997.

Huang, C., Luo, M. T., Chen, X. F., Xiong, L., Li, X. M., and Chen, X. De. 2017. Recent Advances and Industrial Viewpoint for Biological Treatment of Wastewaters by Oleaginous Microorganisms. *Bioresource Technology*, **232**: 398–407.

Huang, Y., Du, J. R., Zhang, Y., Lawless, D., and Feng, X. 2015. Removal of Mercury (II) from Wastewater by Polyvinylamine-Enhanced Ultrafiltration. *Separation and Purification Technology*, **154**: 1–10.

Huang, Y., Wu, D., Wang, X., Huang, W., Lawless, D., and Feng, X. 2016. Removal of Heavy Metals from Water Using Polyvinylamine by Polymer-Enhanced Ultrafiltration and Flocculation. *Separation and Purification Technology*, **158**: 124–136.

Ioannidou, O., and Zabaniotou, A. 2007. Agricultural Residues as Precursors for Activated Carbon Production-A Review. *Renewable and Sustainable Energy Reviews*, **11**(9): 1966–2005.

Ismaiel, A. A., Aroua, M. K., and Yusoff, R. 2013. Palm Shell Activated Carbon Impregnated With Task-Specific Ionic-Liquids as a Novel Adsorbent for the Removal of Mercury from Contaminated Water. *Chemical Engineering Journal*, **225**: 306–314.

Jafari, S. A., and Cheraghi, S. 2014. Mercury Removal from Aqueous Solution by Dried Biomass of Indigenous Vibrio Parahaemolyticus PG02: Kinetic, Equilibrium, and Thermodynamic Studies. *International Biodeterioration & Biodegradation*, **92**: 12–19.

Jafer, H., Atherton, W., Sadique, M., Ruddock, F., and Loffill, E. 2017. Stabilisation of Soft Soil Using Binary Blending of High Calcium Fly Ash and Palm Oil Fuel Ash. *Applied Clay Science*, **152**: 323–332.

Jamo, U., Abdu, S. G., and Pahat, B. 2015. Characterization of a Treated Palm Oil Fuel Ash, **10**(1): 27–31.

Järup, L. 2003. Hazards of heavy metal contamination. *British Medical Bulletin*, **68**: 167–182.

Jeon, C. 2017. Adsorption and Recovery of Immobilized Coffee Ground Beads for Silver Ions from Industrial Wastewater. *Journal of Industrial and Engineering Chemistry*, **53**: 261–267.

Johari, K., Saman, N., Tien, S. S., Chin, C. S., Kong, H., and Mat, H. 2016. Removal of Elemental Mercury by Coconut Pith Char Adsorbents. *Procedia Engineering*, **148**: 1357–1362.

Kadirvelu, K., Thamaraiselvi, K., and Namasivayam, C. 2001. Removal of Heavy Metals from Industrial Wastewaters by Adsorption onto Activated Carbon Prepared from an Agricultural Solid Waste. *Bioresource Technology*, **76**(1): 63–65.

Kazemi, F., Younesi, H., Ghoreyshi, A. A., Bahramifar, N., and Heidari, A. 2016. Thiol-Incorporated Activated Carbon Derived from Fir Wood Sawdust as an Efficient Adsorbent for the Removal Of Mercury Ion: Batch and Fixed-Bed Column Studies. *Process Safety and Environmental Protection*, **100**: 22–35.

Khaloo, S. S., Matin, A. H., Sharifi, S., Fadaeinia, M., Kazempour, N., and Mirzadeh, S. 2012. Equilibrium, Kinetic and Thermodynamic Studies of Mercury Adsorption on Almond Shell. *Water Science and Technology*, **65**(8): 1341–1349.

Khan, M. I., Azizli, K., Sufian, S., Man, Z., and Khan, A. S. 2015. Simultaneous Preparation of Nano Silica and Iron Oxide from Palm Oil Fuel Ash and Thermokinetics of Template Removal. *Rsc Advances*, **5**(27): 20788–20799.

Khanday, W. A., Marrakchi, F., Asif, M., and Hameed, B. H. 2017. Mesoporous Zeolite–Activated Carbon Composite from Oil Palm Ash as an Effective Adsorbent for Methylene Blue. *Journal of the Taiwan Institute of Chemical Engineers*, **70**: 32–41.

Kimberly Huber. 1997. Mercury Use: Wastewater Treatment Plants. In *Draft Wisconsin Mercury Sourcebook: Wastewater Plants* (pp. 602–627).

Kipcak, A. S., Acarali, N. B., Kolemen, S., Tugrul, N., Derun, E. M., Piskin, S., and Materials, A. 2012. Study on Characterization of Tuncbilek Fly Ash, **6**(7): 892–895.

Kiran, M. G., Pakshirajan, K., and Das, G. 2017. An Overview of Sulfidogenic Biological Reactors for the Simultaneous Treatment of Sulfate and Heavy Metal Rich Wastewater. *Chemical Engineering Science*, **158**: 606–620.

Kondapalli, S., and Mohanty, K. 2011. Influence of Temperature on Equilibrium, Kinetic and Thermodynamic Parameters of Biosorption of Cr(VI) onto Fish Scales as Suitable Biosorbent. *Journal of Water Resource and Protection*, **03**(06): 429–439.

Kraber, S., Whitcomb, P., and Anderson, M. 2005. *Handbook for Experimenters Version 06.8. Minneapolis: Stat-Ease, Inc.*

Kumar, D., Kumar, B., and Purkait, M. K. 2013. Removal of Mercury (II) from Aqueous Solution using Bamboo Leaf Powder : Equilibrium , Thermodynamic and Kinetic Studies. *Biochemical Pharmacology*, **1**(4): 891–898.

Kuncoro, E. P., and Fahmi, M. Z. 2013. Removal of Hg and Pb in Aqueous Solution using Coal Fly Ash Adsorbent. *Procedia Earth and Planetary Science*, **6**: 377–382.

Kuśmierek, K., and Świątkowski, A. 2015. The Influence of Different Agitation Techniques on the Adsorption Kinetics Of 4-Chlorophenol on Granular Activated Carbon. *Reaction Kinetics, Mechanisms and Catalysis*, **116**(1): 261–271.

Kwiatkowski, M., and Broniek, E. 2017. An Analysis of the Porous Structure of Activated Carbons Obtained from Hazelnut Shells by Various Physical and Chemical Methods of Activation. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, **529**: 443–453.

Labidi, N. S. 2008. Removal of Mercury from Aqueous Solutions by Waste Brick. *International Journal of Environmental Research*, **2**(3): 275–278.

Li, H., Shi, L., Wang, D., and Wang, M. 2015. Impacts of Mercury Exposure on Life History Traits of Tigriopus Japonicus: Multigeneration Effects and Recovery From Pollution. *Aquatic Toxicology*, **166**: 42–49.

Li, Y., Xu, Z., Liu, S., Zhang, J., and Yang, X. 2017. Molecular Simulation of Reverse Osmosis for Heavy Metal Ions Using Functionalized Nanoporous Graphenes. *Computational Materials Science*, **139**: 65–74.

Liu, C., Cheng, W., Zeng, Q., Huang, X., and Wang, L. 2017. Voltammetric and Microscopical Investigation of the Properties and Behaviors of Individual Mercury Micro-Droplets. *Journal of Electroanalytical Chemistry*, **784**: 145–152.

Liu, M., Hou, L. A., Xi, B., Zhao, Y., and Xia, X. 2013. Synthesis, Characterization, and Mercury Adsorption Properties of Hybrid Mesoporous Aluminosilicate Sieve Prepared with Fly Ash. *Applied Surface Science*, **273**: 706–716.

Lu, X., Huangfu, X., Zhang, X., Wang, Y., and Ma, J. 2015. Removal of Trace Mercury (II) from Aqueous Solution by In Situ Mnox Combined with Poly-Aluminum Chloride. *Journal of Water and Health*, **13**(2): 383–393.

Marthala, V. R. R., Jiang, Y., Huang, J., Wang, W., and Hunger, M. 1995. Preparation of Materials, **25**(I): 5–8.

Martin, R. J., and Iwuco, K. O. 1982. The Effects of pH and Suspended Solids in the Removal of Organics from Waters and Wastewaters by the Activated Carbon Adsorption Process. *Water Research*, **16**(1): 73–82.

Matsuyama, A., Yano, S., Taninaka, T., Kindaichi, M., Sonoda, I., Tada, A., and Akagi, H. 2017. Chemical Characteristics of Dissolved Mercury in the Pore Water of Minamata Bay Sediments. *Marine Pollution Bulletin*, (October): 0–1.

Mazumder, M. A. J., Alhaffar, M. T., and Ali, S. A. 2018. Immobilization of Two Polyelectrolytes Leading to a Novel Hydrogel For High-Performance Hg^{2+} Removal to ppb And Sub-ppb Levels. *Chemical Engineering Journal*, **334**: 1440–1454.

Meena, A. K., Mishra, G. K., Kumar, S., and Rajagopal, C. 2004. Low Cost Adsorbents for the Removal of Mercury (II) from Aqueous Solution- A Comparative Study. *Defence Science Journal*, **54**(4): 537–548.

Meski, S., Ziani, S., Khireddine, H., Boudboub, S., and Zaidi, S. 2011. Factorial Design Analysis for Sorption of Zinc on Hydroxyapatite. *Journal of Hazardous Materials*, **186**(2–3): 1007–1017.

Mondal, D. K., Nandi, B. K., and Purkait, M. K. 2013. Removal of Mercury (II) from Aqueous Solution using Bamboo Leaf Powder: Equilibrium, Thermodynamic and Kinetic Studies. *Journal of Environmental Chemical Engineering*, **1**(4): 891–898.

Mu'azu, N. D., Haladu, S. A., Jarrah, N., Zubair, M., Essa, M. H., and Ali, S. A. 2018. Polyaspartate Extraction of Cadmium Ions from Contaminated Soil: Evaluation and Optimization using Central Composite Design. *Journal of Hazardous Materials*, **342**: 58–68.

Nouri, R., Tahmasebi, E., and Morsali, A. 2017. Capability of Magnetic Functional Metal-Organic Nanocapsules for Removal of Mercury(II) Ions. *Materials Chemistry and Physics*, **198**: 310–316.

Nyale, S. M., Babajide, O. O., Birch, G. D., Böke, N., and Petrik, L. F. 2013. Synthesis and Characterization of Coal Fly Ash-based Foamed Geopolymer. *Procedia Environmental Sciences*, **18**: 722–730.

Oehmen, A., Vergel, D., Fradinho, J., Reis, M. A. M., Crespo, J. G., and Velizarov, S. 2014. Mercury Removal from Water Streams Through the Ion Exchange Membrane Bioreactor Concept. *Journal of Hazardous Materials*, **264**: 65–70.

Oveisi, F., Nikazar, M., Razzaghi, M. H., Mirrahimi, M. A.-S., and Jafarzadeh, M. T. 2017. Effective Removal of Mercury from Aqueous Solution using Thiol-Functionalized Magnetic Nanoparticles. *Environmental Nanotechnology, Monitoring & Management*, **7**: 130–138.

Peters, R. W., and Shem, L. 1993. *Separation of Heavy Metals: Removal from Industrial Wastewaters and Contaminated Soil*. Argonne National Laboratory.

Pourakbar, S. 2015. *Use Of Alkali-Activated Palm Oil Fuel Ash Reinforced by Microfibres for Soft Soil Stabilisation*. Universiti Putra Malaysia.

Pourakbar, S., Asadi, A., Huat, B. B. K., and Fasihnikoutalab, M. H. 2015. Stabilization of Clayey Soil using Ultrafine Palm Oil Fuel Ash (POFA) and Cement. *Transportation Geotechnics*, **3**: 24–35.

Qu, Z., Fang, L., Chen, D., Xu, H., and Yan, N. 2017. Effective and Regenerable Ag/Graphene Adsorbent for Hg(II) Removal from Aqueous Solution. *Fuel*, **203**: 128–134.

Rahbar, N., Jahangiri, A., Boumi, S., and Khodayar, M. J. 2014. Mercury Removal from Aqueous Solutions with Chitosan-Coated Magnetite Nanoparticles Optimized using the Box-Behnken Design. *Jundishapur Journal of Natural Pharmaceutical Products*, **9**(2).

Rahman, M. T., Hainin, M. R., and Bakar, W. A. W. A. 2017. Use of Waste Cooking Oil, Tire Rubber Powder and Palm Oil Fuel Ash in Partial Replacement of Bitumen. *Construction and Building Materials*, **150**: 95–104.

Rajamohan, N. 2014. Biosorption of Mercury onto Protonated Pistachio Hull Wastes – Effect of Variables and Kinetic Experiments. *International Journal of Chemical Engineering and Application*, **5**(5): 415–419.

Rajamohan, N., and Al-sinani, J. 2016. Removal of Boron using Clay-Effect of Process Parameters , Kinetic and Isotherm Studies. *Journal of Engineering Science and Technology*, **11**(3): 311–326.

Rio, S., and Delebarre, A. 2003. Removal of Mercury in Aqueous Solution by Fluidized Bed Plant Fly Ash. *Fuel*, **82**(2): 153–159.

Ruthven, D. M. 1984. *Principles of Adsorption and Adsorption Processes*. New York: John Wiley & Sons.

Şahan, T., Erol, F., and Yılmaz, Ş. 2018. Mercury(II) Adsorption by a Novel Adsorbent Mercapto-Modified Bentonite using ICP-OES and Use Of Response Surface Methodology for Optimization. *Microchemical Journal*, **138**: 360–368.

Saharudin, K. A., Basiron, N., Chun, L. K., Sreekantan, S., Kumaravel, V., Abdullah, T. K., and Ahmad, Z. A. 2017. Improved Super-Hydrophobicity of Eco-Friendly Coating from Palm Oil Fuel Ash (POFA) Waste. *Surface and Coatings Technology*, 1–33.

Saini, R., and Kumar, P. 2016. Optimization of Chlorpyrifos Degradation by Fenton Oxidation Using CCD and ANFIS Computing Technique. *Journal of Environmental Chemical Engineering*, **4**(3): 2952–2963.

Saleh, T. A., Sari, A., and Tuzen, M. 2017. Optimization of Parameters with Experimental Design for the Adsorption of Mercury using Polyethylenimine Modified-Activated Carbon. *Journal of Environmental Chemical Engineering*, **5**(1): 1079–1088.

Samad, K. A., and Zainol, N. 2017. The Use of Factorial Design for Ferulic Acid Production by Co-Culture. *Industrial Crops and Products*, **95**: 202–206.

Senthamilselvan, D., Chezhian, A., Kabilan, N., Suresh, T., and N, S. K. 2012. FTIR Study of Nickel and Mercury Induced Biochemical Changes in the Muscles Tissues of Lates Calcarifer, **2**(4): 1976–1983.

Shafeeq, A., Muhammad, A., Sarfraz, W., Toqeer, A., Rashid, S., and Rafiq, M. K. 2012. Mercury Removal Techniques for Industrial Waste Water, **6**(12): 1197–1200.

Shamsuddin, N., Das, D. B., and Starov, V. M. 2015. Filtration of Natural Organic Matter using Ultrafiltration Membranes for Drinking Water Purposes : Circular Cross-Flow Compared with Stirred Dead End Flow. *Chemical Engineering Journal*, **276**: 331–339.

Sharma, A., Sharma, A., and Arya, R. K. 2015. Removal of Mercury(II) from Aqueous Solution: A Review of Recent Work. *Separation Science and Technology*, **50**(9): 1310–1320.

Sharma, J., Sukriti, Anand, P., Pruthi, V., Chaddha, A. S., Bhatia, J., and Kaith, B. S. 2017. RSM-CCD Optimized Adsorbent for the Sequestration of Carcinogenic Rhodamine-B: Kinetics and Equilibrium Studies. *Materials Chemistry And Physics*, **196**: 270–283.

Shen, B., Tian, L., Li, F., Zhang, X., Xu, H., and Singh, S. 2017. Elemental Mercury Removal by the Modified Bio-Char From Waste Tea. *Fuel*, **187**: 189–196.

Shenvi, S. S., Isloor, A. M., Ahmad, A. L., Garudachari, B., and Ismail, A. F. 2016. Influence of Palm Oil Fuel Ash, an Agro-Industry Waste on the Ultrafiltration Performance of Cellulose Acetate Butyrate Membrane. *Desalination and Water Treatment*, **57**(55): 26414–26426.

Shirkhanloo, H., Osanloo, M., Ghazaghi, M., and Hassani, H. 2016. Validation of a New and Cost-Effective Method for Mercury Vapor Removal Based on Silver Nanoparticles Coating on Micro Glassy Balls. *Atmospheric Pollution Research*.

Silva, H. S., Ruiz, S. V., Granados, D. L., and Santángelo, J. M. 2010. Adsorption of Mercury (II) from Liquid Solutions Using Modified Activated Carbons. *Materials Research*, **13**(2): 129–134.

Singha Deb, A. K., Dwivedi, V., Dasgupta, K., Musharaf Ali, S., and Shenoy, K. T. 2017. Novel Amidoamine Functionalized Multi-Walled Carbon Nanotubes for Removal of Mercury(II) Ions from Wastewater: Combined Experimental and Density Functional Theoretical Approach. *Chemical Engineering Journal*, **313**: 899–911.

Sobahan, M. A., Mir, S. I., Zakaria, I., Hossain, M. A., and Area, A. S. 2013. Surface Water Contamination Due to Industrial Activities in Gebeng Area , Kuantan , Malaysia. In *International Conference on Civil and Architecture Engineering (ICCAE'2013)* (pp. 53–61).

Soleimani, M., and Siahpoosh, Z. H. 2015. Ghezeljeh Nanoclay as a New Natural Adsorbent for the Removal of Copper and Mercury Ions: Equilibrium, Kinetics and Thermodynamics Studies. *Chinese Journal of Chemical Engineering*, **23**(11): 1819–1833.

Somerset, V., Petrik, L., and Iwuoha, E. 2008. Alkaline Hydrothermal Conversion of Fly Ash Precipitates Into Zeolites : The Removal of Mercury and Lead Ions from Wastewater. *Journal of Environmental Management*, **87**(1): 125–131.

Stylianou, S. K., Sklari, S. D., Zamboulis, D., Zaspalis, V. T., and Zouboulis, A. I. 2015. Development of Bubble-Less Ozonation and Membrane Filtration Process for the Treatment of Contaminated Water. *Journal of Membrane Science*, **492**: 40–47.

Sun, Y., Lv, D., Zhou, J., Zhou, X., Lou, Z., Baig, S. A., and Xu, X. 2017. Adsorption of Mercury (II) from Aqueous Solutions using Fes and Pyrite: A Comparative Study. *Chemosphere*, **185**: 452–461.

Tang, Y. P., Luo, L., Thong, Z., and Chung, T. S. 2017. Recent Advances in Membrane Materials and Technologies for Boron Removal. *Journal of Membrane Science*, **541**: 434–446.

Thomas, B. S., Kumar, S., and Arel, H. S. 2017. Sustainable Concrete Containing Palm Oil Fuel Ash as a Supplementary Cementitious Material – A Review. *Renewable and Sustainable Energy Reviews*, **80**: 550–561.

Tran, L., Wu, P., Zhu, Y., Yang, L., and Zhu, N. 2015. Highly Enhanced Adsorption for the Removal of Hg(II) from Aqueous Solution by Mercaptoethylamine/Mercaptopropyltrimethoxysilane Functionalized Vermiculites. *Journal of Colloid and Interface Science*, **445**: 348–356.

Verma, V. K., and Tripathi, I. N. 2014. Kinetic Study on the Removal of Mercury by Fly Ash. *Global NEST Journal*, **16**(2): 385–392.

Wahi, R., Ngaini, Z., and Jok, V. 2009. Removal of Mercury, Lead and Copper from Aqueous Solution by Activated Carbon of Palm Oil Empty Fruit Bunch. *World Applied Sciences Journal*, **5**((special issue for environment)): 84–91.

Wang, A., Zhou, K., Liu, X., Liu, F., Zhang, C., and Chen, Q. 2017. Granular Tri-Metal Oxide Adsorbent for Fluoride Uptake: Adsorption Kinetic and Equilibrium Studies. *Journal of Colloid and Interface Science*, **505**: 947–955.

Wang, D., Guo, F., Wu, Y., Li, Z., and Wu, G. 2018. Technical, Economic and Environmental Assessment of Coagulation/Filtration Tertiary Treatment Processes in Full-Scale Wastewater Treatment Plants. *Journal of Cleaner Production*, **170**: 1185–1194.

Wei, I. T. A. 2008. *Preparation , Characterization and Evaluation of Mesoporous Activated Carbons Derived from Agricultural by-Products for Adsorption of Methylene Blue and 2,4,6- Trichlorophenol*. Universiti Sains Malaysia.

Xu, M., Yin, P., Liu, X., Dong, X., Yang, Y., Wang, Z., and Qu, R. 2013. Optimization of Biosorption Parameters of Hg(II) from Aqueous Solutions by the Buckwheat Hulls using Respond Surface Methodology. *Desalination and Water Treatment*, **51**(22–24): 4546–4555.

Xu, P., Luo, G., Zhang, B., Zeng, X., Xu, Y., Zou, R., … Yao, H. 2017. Influence of Low Pressure on Mercury Removal from Coals Via Mild Pyrolysis. *Applied Thermal Engineering*, **113**: 1250–1255.

Xu, W., Wang, H., Zhu, T., Kuang, J., and Jing, P. 2013. Mercury Removal from Coal Combustion Flue Gas by Modified Fly Ash. *Journal of Environmental Sciences (China)*, **25**(2): 393–398.

Yahya, Z., Abdullah, M. M. A. B., Hussin, K., Ismail, K. N., Sandu, A. V., Vizureanu, P., and Razak, R. A. 2013. Chemical and Physical Characterization of Boiler Ash from Palm Oil Industry Waste for Geopolymer Composite. *Rev. Chim. (Bucharest)*, (12): 32–34.

Yang, T., and Lua, A. C. 2003. Characteristics of Activated Carbons Prepared from Pistachio-Nut Shells by Potassium Hydroxide Activation. *Microporous and Mesoporous Materials*, **63**(1–3): 113–124.

Yang, W., Liu, Z., Xu, W., and Liu, Y. 2018. Removal of Elemental Mercury from Flue Gas using Sargassum Chars Modified by NH4Br Reagent. *Fuel*, **214**: 196–206.

Yao, C., Jin, S., Shen, X., Chen, S., Zhang, C., and Sun, Y. 2009. The Effect of Agitation on Volatilization of Naphthalene from Solution Containing Surfactant. *Journal of Hazardous Materials*, **164**(1): 195–203.

Yavuz, Y., and Ogütveren, Ü. B. 2018. Treatment of Industrial Estate Wastewater by the Application of Electrocoagulation Process using Iron Electrodes. *Journal of Environmental Management*, **207**: 151–158.

Zabihi, M., Ahmadpour, A., and Haghighi Asl, A. 2009. Removal of Mercury from Water by Carbonaceous Sorbents Derived from Walnut Shell. *Journal of Hazardous Materials*, **167**(1–3): 230–236.

Zarina, Y., Bakri, A. M. M. Al, Kamarudin, H., Nizar, I. K., and Rafiza, A. R. 2013. Review on The Various Ash from Palm Oil Waste as Geopolymer Material. *Rev. Adv. Mater. Sci*, **34**: 37–43.

Zhang, A., Xing, W., Zhang, Z., Meng, F., Liu, Z., Xiang, J., and Sun, L. 2016. Promotional Effect of SO_2 on CeO_2–TiO_2 Material for Elemental Mercury Removal at Low Temperature. *Atmospheric Pollution Research*, **7**(5): 895–902.

Zhang, Q., Liu, N., Cao, Y., Zhang, W., Wei, Y., and Feng, L. 2018. A Facile Method to Prepare Dual-Functional Membrane for Efficient Oil Removal and In Situ Reversible Mercury Ions Adsorption from Wastewater. *Applied Surface Science*, **434**: 57–62.

Zhou, G., Liu, C., Chu, L., Tang, Y., and Luo, S. 2016. Rapid and Efficient Treatment of Wastewater with High-Concentration Heavy Metals using a New Type of Hydrogel-Based Adsorption Process. *Bioresource Technology*, **219**: 451–457.

Zhu, Y., Zheng, Y., Wang, W., and Wang, A. 2015. Highly Efficient Adsorption of Hg(II) and Pb(II) onto Chitosan-Based Granular Adsorbent Containing Thiourea Groups. *Journal of Water Process Engineering*, **7**: 218–226.