SULFIDE REMOVAL FROM PETROLEUM REFINERY WASTEWATER USING HYDROGEN PEROXIDE AND CHEMICALLY MODIFIED ACTIVATED CARBON

MARIAH BINTI CHE MAMAT

MASTER OF SCIENCE

UNIVERSITI MALAYSIA PAHANG

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis, and, in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science.

(Supervisor's Signature)

Full Name : DR ABDUL AZIZ BIN MOHD AZODDEIN

Position : PROFESOR MADYA

Date : 18/4/2022

STUDENT'S DECLARATION

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

(Student's Signature)

Full Name : MARIAH BINTI CHE MAMAT

ID Number : MKC16010

Date : 18/4/2022

SULFIDE REMOVAL FROM PETROLEUM REFINERY WASTEWATER USING HYDROGEN PEROXIDE AND CHEMICALLY MODIFIED ACTIVATED CARBON

MARIAH BINTI CHE MAMAT

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Master of Science

Faculty of Industrial Sciences and Technology
UNIVERSITI MALAYSIA PAHANG

APRIL 2022

ACKNOWLEDGEMENTS

Assalamualaikum and greetings. First of all, I would like to express my foremost gratefulness to Allah S.W.T. for His grace, leading and guidance.

I would like to express my deepest gratitude to my main supervisor, Dr Abdul Aziz Bin Mohd Azoddein for his patience, his persistent push for perfectionism and professionalism, his trust in my abilities and his confidence in me. I am grateful to who have supported me to make this work a success, Mr Omeer Habeed and Mr Mohamad Zaki Sahad for their continuous guidance and particularly leading me to the world of this research.

I am grateful to the Faculty of Chemical and Process Engineering Technology, University Malaysia Pahang (UMP) for the support and facilities provided to carry out the experimental work. I also appreciate the financial support for this Master project and sponsoring my conference provided by Universiti Malaysia Pahang (UMP) with Vot Number PGRS170326.

I would also like to extend my special gratitude is to Ms. Munirah ezzah, Mrs Nadja Julika, Ms. Najahusna, Ms. Aisyah, Ms. Elyana Husna, Ms. Farhani, Ms. Faten, Mr Tahfiz, Mr Hamzah and Mr Wan Syafiq for their inspiration, support and also for their friendship and kindness in my life. Last but not least, special appreciation goes out to my beloved family members, for their love, endless support, understanding and encouragement during my pursuit of the Master of Science.

ABSTRAK

Loji penapisan petroleum menjana air sisa, sisa pepejal dan enap cemar yang terdiri daripada sebatian organik, bukan organik termasuk logam berat. Rawatan lanjut diperlukan untuk sisa kilang penapisan petroleum kerana ia biasanya mempunyai kandungan sulfida yang tinggi yang dikenali sebagai bahan pencemar yang paling berbahaya. Ia dilepaskan ke persekitaran sebagai sulfida terlarut (S^{2-} dan HS^{-}) dalam effluen dan H_2S dalam gas sisa. Oleh itu, penyingkiran sulfida dari kilang penapis minyak petroleum adalah sangat penting kerana ianya boleh mendatangkan bahaya kepada masalah manusia dan persekitaran disebabkan kealkalian dan tahap sulfida yang tinggi. Objektif dalam kajian ini adalah untuk mengetahui kemampuan hidrogen perokside (H_2O_2) dan karbon teraktif diubah suai secara kimia (AC-M) sebagai kajian pendekatan baru dalam penyingkiran sulfida dari sisa kilang penapisan petroleum. Kesan daripada pencemar berbahaya ini menjadi kebimbangan yang semakin meningkat terhadap isu-isu alam sekitar disebabkan pengaliran sulfida dari sisa kilang penapisan petroleum dengan melalui kaedah pengoksidaan dan kaedah penjerapan dalam kajian ini. Keputusan menunjukkan kepekatan sulfida dalam simulasi air sisa yang terbaik adalah 300 mg/L, dos H_2O_2 adalah 1.5 ml dan masa tindak balas adalah 30 minit dalam proses pengoksidaan. Walau bagaimanapun, kepekatan sulfida dalam simulasi air sisa yang terbaik adalah 100 mg/L, jumlah berat AC-M adalah 0.5 g dan masa sentuh adalah 6 jam dalam proses penjerapan. Ciri-ciri AC-M yang disediakan akan dianalisis menggunakan SEM, EDX, BET, dan FTIR. Kajian kinetik mengenai keadaan penjerapan AC-M telah menunjukkan bahawa isotherm penjerapan Freundlich lebih sesuai dan proses penjerapan mengikuti model kinetik urutan Pseudo-kedua. Perbandingan antara kaedah pengoksidaan dan penjerapan dengan menggunakan parameter terbaik dalam pengurangan sulfida dari sisa kilang penapis petroleum sebenar telah ditentukan. Kecekapan kaedah pengoksidaan yang mampu mengurangkan kepekatan sulfida adalah 99.83% daripada 300 mg/L kepada 0.5 mg/L, kepekatan COD adalah 98.29% daripada 4100 mg/L kepada 70 mg/L dan pH adalah 29.08% daripada 11.86 kepada 8.41. Walau bagaimanapun, kecekapan kaedah penjerapan dalam pengurangan kepekatan sulfida adalah 95.70% daripada 100 mg/L kepada 4.3 mg/L, kepekatan COD adalah 98.29% daripada 4100 mg/L kepada 70 mg/L, dan pH adalah 3.0% daripada 12.00 kepada 11.65. Oleh itu, disimpulkan bahawa kaedah pengoksidaan lebih berkesan daripada kaedah penjerapan dalam penyingkiran sulfida daripada sisa air kaustik. Bagaimanapun, kedua-dua kaedah tersebut boleh meyingkirkan lebih daripada 90% terutamanya pada kepekatan sulfida dan COD. Ianya mencadangkan pengunaan kaedah pengoksidaan hibrid bersama kaedah penjerapan untuk mendapatkan lebih keberkesanan dalam penyingkiran sulfida. Maklumat yang diperolehi daripada kajian ini berguna untuk tujuan skala dalam industri penapisan petroleum.

ABSTRACT

Petroleum refinery plants generate wastewater, solid waste and sludge composed of organic, inorganic compounds including heavy metals. Further treatment is needed for petroleum refinery wastewater because it typically has high concentration of sulfide which is known as the most hazardous pollutants. It is released to environment as dissolved sulfide (S^{2-} and HS^-) in effluents and H_2S in waste gases. Thus, it is very important to remove sulfide from petroleum refinery wastewater that can bring harmful to human and environmental problems because of their alkalinity and high sulfide level. The objective in this study is to determine the ability of hydrogen peroxide (H_2O_2) and chemically modified activated carbon (AC-M) as a new approach studies in sulfide removal from petroleum refinery wastewater. The effect caused by these hazardous pollutants and growing concern on environmental issues led to remove sulfide from petroleum refinery wastewater using oxidation method and adsorption method in this study. Result shows the best concentration of sulfide simulated wastewater is 300 mg/L, H_2O_2 dosage is 1.5 ml and reaction time is 30 min in oxidation process. While, the best concentration of sulfide simulated wastewater is 100 mg/L, AC-M dosage is 0.5 g and contact time is 6 hr in adsorption process. The prepared AC-M was characterized using SEM, EDX, BET, and FTIR. The kinetic studies of the adsorption behaviour of AC-M have shown that Freundlich adsorption isotherm is fitted well and the adsorption process followed Pseudo-second order kinetic model. The comparative between oxidation and adsorption method using the best parameters on sulfide removal from actual petroleum refinery wastewater was determined. The efficiency of oxidation method which is able to remove sulfide concentration is 99.83% from 300 mg/L to 0.5 mg/L, COD concentration is 98.29% from 4100 mg/L to 70 mg/L, and pH is 29.08% from 11.86 to 8.41. While, the efficiency of adsorption method which is able to remove sulfide concentration is 95.70% from 100 mg/L to 4.3 mg/L, COD concentration is 98.29% from 4100 mg/L to 70 mg/L, and pH is 3.0% from 12.00 to 11.65. Thus, it is concluded that oxidation method more effective than adsorption method in sulfide removal from spent caustic. However, both methods were able to remove more than 90% removal especially on sulfide and COD concentration. It is recommended that oxidation method hybrid with adsorption method to provide more efficiency of sulfide removal. The information obtained from this study is useful for scale up purpose in the petroleum refining industry.

TABLE OF CONTENT

REFERENCES

Abdel Ghafar, H. H., Ali, G. A. M., Fouad, O. A., & Makhlouf, S. A. (2013). Enhancement of adsorption efficiency of methylene blue on Co_3O_4/SiO_2 nanocomposite. *Journal of Desalination and Water Treatment*, 53(11), 37-41.

Abdullah, N., Abdul Aziz, H., Yusuf, N. N. A., Umar, M., & Abu Amr, S. S. (2014). Potential of $KMnO_4$ and H_2O_2 in treating semi-aerobic landfill leachate. *Journal of Applied Water Science*, 4(3), 303-309.

Agarwal, S., Sadegh, H., Monajjemi, M., Salam, A., Ali, G. A. M., Memar, A. O. H., & Kumar, V. (2016). Efficient removal of toxic bromothymol blue and methylene blue from wastewater by polyvinyl alcohol. *Journal of Molecular Liquids*, 218, 191-197.

Ahmad, W. (2010). Neutralization of spent caustic from LPG plant at Preem AB Göteborg. Master Thesis. Chalmers University of Technology, Sweden.

Al-degs, Y. S., El-barghouthi, M. I., El-sheikh, A. H., & Walker, G. M. (2008). Effect of solution pH, ionic strength, and temperature on adsorption behavior of reactive dyes on activated carbon. *Journal of Dyes and Pigments*, 77(1), 16-23.

Allen, S. J., & Koumanova, B. (2005). Decolourisation of water/wastewater using adsorption. *Journal of the University of Chemical Technology and Metallurgy*, 40(3), 175-192.

Allen, S. J., Whitten, L. J., Murray, M., Duggan, O., & Brown, P. (1997). The adsorption of pollutants by peat , lignite and activated chars. J*ournal of Chemical Technology & Biotechnology: International Research in Process, Environmental and Clean Technology*, 68(4), 442-452.

Alnaizy, R. (2008). Economic analysis for wet oxidation processes for the treatment of mixed refinery spent caustic. *Environmental Progress*, 27(3), 295-301.

Alonso-Vicario, A., Ochoa-Gómez, J. R., Gil-Río, S., Gómez-Jiménez-Aberasturi, O., Ramírez-López, C. A., Torrecilla-Soria, J., & Domínguez, A. (2010). Purification and upgrading of biogas by pressure swing adsorption on synthetic and natural zeolites. *Microporous and Mesoporous Materials*, 134(1-3), 100-107.

ALOthman, Z. A. (2012). A review: fundamental aspects of silicate mesoporous materials. *Materials*, 5(12), 2874-2902.

Altaş, L., & Büyükgüngör, H. (2008). Sulfide removal in petroleum refinery wastewater by chemical precipitation. *Journal of Hazardous Materials*, 153(1-2), 462-469.

Amosa, M. K., Jami, M. S., & Alkhatib, M. F. R. (2016). Electrostatic biosorption of COD, Mn and H_2S on EFB-based activated carbon produced through steam pyrolysis: an analysis based on surface chemistry, equilibria and kinetics. *Waste and Biomass Valorization*, 7(1), 109-124.

Arief, V. O., Trilestari, K., Sunarso, J., Indraswati, N., & Ismadji, S. (2008). Recent progress on biosorption of heavy metals from liquids using low cost biosorbents: characterization, biosorption parameters and mechanism studies. *CLEAN-Soil, Air, Water*, 36(12): 937-962.

Badmus, M. A. O., Audu, T. O. K., & Anyata, B. U. (2007). Removal of heavy metal from industrial wastewater using hydrogen peroxide. *African Journal of Biotechnology*, 6(3), 238-242.

Bae, J. W., Kang, S. H., Dhar, G. M., & Jun, K. W. (2009). Effect of Al_2O_3 content on the adsorptive properties of $Cu/ZnO/Al_2O_3$ for removal of odorant sulfur compounds. *International Journal of Hydrogen Energy*, 34(20), 8733-8740.

Ballerino-Regan, D., & Longmire, A. W. (2010). Hydrogen sulfide exposure as a cause of sudden occupational death. *Archives of Pathology & Laboratory Medicine*, 134(8), 1105-1105.

Belmabkhout, Y., De Weireld, G., & Sayari, A. (2009). Amine-bearing mesoporous silica for CO_2 and H_2S removal from natural gas and biogas. *Langmuir*, 25(23), 13275-13278.

Hariz, I. B., Halleb, A., Adhoum, N., & Monser, L. (2013). Treatment of petroleum refinery sulfidic spent caustic wastes by electrocoagulation. *Separation and Purification Technology*, 107, 150-157.

Brunauer, S., Emmett, P. H., & Teller, E. (1938). Adsorption of gases in multimolecular layers. *Journal of the American Chemical Society*, 60(2), 309-319.

Carrott, P. J. M., & Carrott, M. R. (2007). Lignin-from natural adsorbent to activated carbon: a review. *Bioresource Technology*, 98(12), 2301-2312.

Moreno-Castilla, C., & Rivera-Utrilla, J. (2001). Carbon materials as adsorbents for the removal of pollutants from the aqueous phase. *MRS Bulletin*, 26(11), 890-894.

Cavalcanti, J. V. F. L., Abreu, C. A., Carvalho, M. N., Sobrinho, M. A. M., Benachour, M., & Baraúna, O. S. (2012). Removal of effluent from petrochemical wastewater by adsorption using organoclay. *Petrochemicals*, 14, 277-295.

Cechinel, M. A., Mayer, D. A., Pozdniakova, T. A., Mazur, L. P., Boaventura, R. A., de Souza, A. A. U., de Souza, S. M. A. G. U., & Vilar, V. J. P. (2016). Removal of metal ions from a petrochemical wastewater using brown macro-algae as natural cation-exchangers. *Chemical Engineering Journal*, 286, 1–15.

Chakraborty, D., Bhar, S., Majumdar, J., & Santra, S. C. (2013). Heavy metal pollution and Phytoremediation potential of Avicennia officinalis L . in the southern coast of the Hoogly estuarine system, *International Journal of Environmental Sciences*, 3(6), 2291–2303.

Chemicals, S. (2005). Cost-Effective Wastewater Treatment with INTEROX® Hydrogen Peroxide. 1-6.

Chemistry 112 Laboratory. (2005). Precipitation of Metal Sulfides. 17–26.

Choo, H. S., Lau, L. C., Mohamed, A. R., & Lee, K. T. (2013). Hydrogen sulfide adsorption by alkaline impregnated coconut shell activated carbon, *Journal of Engineering Science and Technology*, 8(6), 741-753.

Chowdhury, Z. Z. (2013). Preparation, characterization and adsorption studies of heavy metals onto activated adsorbent materials derived from agricultural residues. PhD Thesis. University of Malaya, Malaysia.

Coca, J., Gutiérrez, G., & Benito, J. (2011). Treatment of oily wastewater. *Water Purification and Management*, 1-55.

D'Alessandro, W., Brusca, L., Kyriakopoulos, K., Michas, G., & Papadakis, G. (2009). Hydrogen sulphide as a natural air contaminant in volcanic/geothermal areas: the case of Sousaki, Corinthia (Greece), *Environmental Geology*, 57(8), 1723-1728.

Dabrowski, A., Podkoscielny, P., Hubicki, Z., & Barczak, M. (2005). Adsorption of phenolic compounds by activated carbon — a critical review, *Chemosphere*, 58(8), 1049-1070.

Daneshfozoun, S., Nazirb, M. S., Abdullaha, B., & Abdullaha, M. A. (2014). Surface modification of celluloses extracted from oil palm empty fruit bunches for heavy metal sorption, *Chemical Engineering*, 37, 679-684.

Dar, P., Dar, A., Ahmed, D., & Dar, A. M. (2017). A comparative biosorption study of sulfide (S^{-2}) by using Lagenaria siceraria fruit based raw biosorbent, *Bangladesh Journal of Scientific and Industrial Research*, 52(4), 309-320.

De Graaff, M., Bijmans, M. F., Abbas, B., Euverink, G. J., Muyzer, G., & Janssen, A. J. (2011). Biological treatment of refinery spent caustics under halo-alkaline conditions, *Bioresource Technology*, 102(15), 7257-7264.

Derylo-marczewska, A., Swiatkowski, A., Biniak, S., & Walczyk, M. (2008). Effect of properties of chemically modified activated carbon and aromatic adsorbate molecule on adsorption from liquid phase, *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 327(1-3), 1-8.

Diya'uddeen, B. H., Daud, W. M. A. W., & Aziz, A. A. (2011). Treatment technologies for petroleum refinery effluents: A review, *Process Safety and Environmental Protection*, 89(2), 95-105.

Edathil, A. A., Pal, P., & Banat, F. (2017). Alginate derived porous graphitic carbon for highly efficient remediation of sulfide from wastewater, *Journal of Environmental Chemical Engineering*, 5(2), 1998-2009.

El-Naas, M. H., Al-Zuhair, S., Al-Lobaney, A., & Makhlouf, S. (2009). Assessment of electrocoagulation for the treatment of petroleum refinery wastewater, *Journal of Environmental Management*, 91(1), 180-185.

El-sayed, Y., & Bandosz, T. J. (2004). Adsorption of valeric acid from aqueous solution onto activated carbons : role of surface basic sites, *Journal of Colloid and Interface Science*, 273(1), 64-72.

Elsayed, Y., Seredych, M., Dallas, A., & Bandosz, T. J. (2009). Desulfurization of air at high and low H_2S concentrations, Chemical Engineering Journal, 155(3), 594-602.

Farzadkia, M., Gholami, M., Kermani, M., & Yaghmaeian, K. (2012). Biosorption of hexavalent chromium from aqueous solutions by chemically modified brown algae of sargassum Sp. and dried activated sludge, *Asian Journal of Chemistry*, 24(11), 5257-5263.

Fazli, N., Mutamim, N. S. A., & Ali, M. F. (2018). Microbial Fuel Cell (MFC) in treating spent caustic wastewater, *Journal Chemical Engineering and Industrial Biotechnology*, 3, 17-25.

Feng, W., Kwon, S., Borguet, E., & Vidic, R. (2005). Adsorption of hydrogen sulfide onto activated carbon fibers : effect of pore structure and surface chemistry, Environmental Science & Technology, 39(24), 9744-9749.

Ficek, K. J. (1980). Potassium permanganate controls sewage odors. Carus Chemical Company, United States.

Fidelis, N. (2015). Adsorption of heavy metals from aqueous solutions using Mangroves from Kenyan coast. Master Thesis. University of Nairobi, Kenya.

Foo, K. Y., & Hameed, B. H. (2010). Insights into the modeling of adsorption isotherm system. *Chemical Engineering Journal*, 156(1), 2-10.

Forero, J. E., Duque, J. J., Rios, F., & Diaz, J. (2001). Ozone for phenol treatment in industrial wastewater, CT&F-Ciencia, Tecnología y Futuro, 2(2), 17-26.

Garba, Z. N., Bello, I., Galadima, A., & 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.

Gulsac, I. I. (2016). Investigation of impregnated activated carbon properties used in hydrogen sulfide fine removal, *Brazilian Journal of Chemical Engineering*, 33(4), 1021-1030.

Guo, J., Luo, Y., Lua, A. C., Chi, R. A., Chen, Y. L., Bao, X. T., & Xiang, S. X. (2007). Adsorption of hydrogen sulphide (H_2S) by activated carbons derived from oil-palm shell, *Carbon*, 45(2), 330-336.

Habeeb, O. A., Kanthasamy, R., Ali, G. A. M., & Mohd, Y. R. (2017). Experimental design technique on removal of hydrogen sulfide using CaO-eggshells dispersed onto palm kernel shell activated carbon : experiment, optimization, equilibrium and kinetic studies, *Journal of Wuhan University Technology-Mater Sci Ed*, 32, 305-32.

Haimour, N., El-Bishtawi, R., & Ail-Wahbi, A. (2005). Equilibrium adsorption of hydrogen sulfide onto CuO and ZnO, *Desalination*, 181(1-3), 145-152.

Hariz, I. B., & Monser, L. (2014). Sulfide removal from petroleum refinery wastewater by adsorption on chemically modified activated carbon, *International Water Technology Journal*, 4(4), 264-267.

Hawari, A., Ramadan, H., Abu-reesh, I., & Ouederni, M. (2015). A comparative study of the treatment of ethylene plant spent caustic by neutralization and classical and advanced oxidation, *Journal of Environmental Management*, 151, 105-112.

Heidarinasab, A., & Hashemi, S. R. (2011). A study of biological treatment of spent sulfidic caustic. *International Conference on Chemical, Ecology and Environmental Sciences (ICCEES 2011)*, 17-18.

Hervy, M., Minh, D. P., Gérente, C., Weiss-hortala, E., Nzihou, A., Villot, A., & Le Coq, L. (2018). H_2S removal from syngas using wastes pyrolysis chars, *Chemical Engineering Journal*, 334, 2179-2189.

Imran, M., Ateeb, M., Khan, M. H., Ahmed, N., & Mahmood, Q. (2016). Integrated treatment of pharmaceutical effluents by chemical coagulation and ozonation, *Separation and Purification Technology*, 158, 383-386.

Ishak, S., Malakahmad, A., & Isa, M. H. (2012). Refinery wastewater biological treatment : A short review, *Journal of Scientific & Industrial Research*, 71, 251-256.

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.

Karimi, A., Fatehifar, E., Alizadeh, R., & Ahadzadeh, I. (2016). Regeneration and treatment of sulfidic spent caustic using analytic hierarchy process, *Environmental Health Engineering and Management Journal*, 3(4), 203-208.

Kazmierczak-Razna, J., Gralak-Podemska, B., Nowicki, P., & Pietrzak, R. (2015). The use of microwave radiation for obtaining activated carbons from sawdust and their potential application in removal of NO_2 and H_2S. *Chemical Engineering Journal*, 269, 352–358.

Kerc, A., & Olmez, S. S. (2010). Ozonation of odorous air in wastewater treatment plants, *Ozone: Science & Engineering*, 32(3), 199-203.

Ksibi, M. (2006). Chemical oxidation with hydrogen peroxide for domestic wastewater treatment, *Chemical Engineering Journal*, 119(2-3), 161-165.

Kumfer, B., Felch, C., & Maugans, C. (2010). Wet air oxidation treatment of spent caustic in petroleum refineries, *National Petroleum Refiner's Association Conference*, Phoenix, AZ (Vol. 23).

Lean Seey, T., & Kassim, M. J. N. M. (2012). Characterization of mangrove bark as a potentially low-cost adsorbent for reactive dye removal from aqueous solutions: equilibrium, mechanisms and kinetics, *International Journal of Pure and Applied Sciences and Technology* , 9(1), 9-19.

Lee, S., Xu, Q., Booth, M., Townsend, T. G., Chadik, P., & Bitton, G. (2006). Reduced sulfur compounds in gas from construction and demolition debris landfills, *Waste Management*, 26(5), 526-533.

Liao, C. H., Lu, M. C., Yang, Y. H., & Lu, I. C. (2000). UV-catalyzed hydrogen peroxide treatment of textile wastewater, *Environmental Engineering Science*, 17(1), 9-18.

Liao, C. H., & Gurol, M. D. (1995). Chemical oxidation by photolytic decomposition of hydrogen peroxide, *Environmental Science & Technology*, 29(12), 3007-3014.

Liu, M., Deng, Q., Zhao, F., & Liu, Y. (2012). Origin of hydrogen sulfide in coal seams in China, *Safety Science*, 50(4), 668-673.

MacFarlane, G. R., & Burchett, M. D. (2002). Toxicity, growth and accumulation relationships of copper, lead and zinc in the grey mangrove Avicennia marina (Forsk.) Vierh, *Marine Environmental Research*, 54(1), 65-84.

Mandy C., G. D., Anthony, W. H., Okorosaye K., O., & Sunday, B. U. (2014). Determination of potassium ion concentration in red mangrove (Rhizophora Mangle L) bark aqueous extract (rmbae) in buffer media, *Archives of Applied Science Research*, 6(6), 61–66.

Maria, E. E. R. (2008). Management of hydrogen sulphide generation at a kraft paper mill. Master Thesis. University of Pretoria, South Africa.

Miah, M. R., Sarker, A., Rahman, M. A., Manny, T. F., & Sen, D. (2017). Conductometric studies of adsorption of sulfide on charcoal from aqueous solution, *International Journal of Scientific & Technology Research*, 6(3), 86-90.

Mohamed, E. F. (2011). Removal of organic compounds from water by adsorption and photocatalytic oxidation. PhD Thesis. University of De toulous, France.

Moreno-castilla, C. (2004). Adsorption of organic molecules from aqueous solutions on carbon materials. *Carbon*, 42(1), 83-94.

MortezaNia, S., and Othman, F. (2016). Dissolved sulfides removal in wastewater collection networks Kuala Lumpur-Malaysia, In *Conference on Energy and Environment (ENVIROENERGY 2009)*. Taj Chandigarh, Chandigarh INDIA, 341-348.

Mota, A. L. N., Albuquerque, L. F., Beltrame, L. T. C., Chiavone-Filho, O., Machulek Jr, A., & Nascimento, C. A. O. (2009). Advanced oxidation processes and their application in the petroleum industry: a review, *Brazilian Journal of Petroleum and Gas*, 2(3), 122-142.

Ngugi, F., Onyari, J. M., & Wabomba, J. N. (2016). Efficacy of mangrove (Rhizophora Mucronata) roots powder in adsorption of lead (II) ions from aqueous solutions: equilibrium and kinetics studies, *IOSR Journal of Applied Chemistry*, 9(8), 45-51.

Nowicki, P., Skibiszewska, P., & Pietrzak, R. (2014). Hydrogen sulphide removal on carbonaceous adsorbents prepared from coffee industry waste materials, *Chemical Engineering Journal*, 248, 208-215.

Occidental Chemical Corporation. (2014). Sodium chlorite and hydrogen sulfide control in wastewater collection systems, 1-3.

Oliveira, R. C., Palmieri, M. C., & Garcia Jr, O. (2011). Biosorption of metals: state of the art, general features, and potential applications for environmental and technological processes In *Progress in Biomass and Bioenergy Production*, 151-177.

Osman, M. A. & Soubaneh, Y. D. (2014). Waste water treatment in chemical industries: the concept and current technologies, *Hydrology: Current Research*, 5(1), 1-12.

Ouasif, H., Yousfi, S., Bouamrani, M. L., El Kouali, M., Benmokhtar, S., & Talbi, M. (2013). Removal of a cationic dye from wastewater by adsorption onto natural adsorbents. *Journal of Materials and Environmental Science*, 4(1), 1-10.

Paulino, J. F., & Alfonso, J. C. (2012). New strategies for treatment and reuse of spent sulfidic caustic streams from petroleum industry, *Química Nova*, 35(7), 1447-1452.

Redi, J. (2002). Oil refinery processes, 1-53.

Sathish, T., Vinithkumar, N. V., Dharani, G., & Kirubagaran, R. (2015). Efficacy of mangrove leaf powder for bioremediation of chromium (VI) from aqueous solutions : kinetic and thermodynamic evaluation, *Applied Water Science*, 5(2), 153-160.

Sattler, M. L., Garrepalli, D. R., & Nawal, C. S. (2012). Carbonyl sulfide removal with compost and wood chip biofilters, and in the presence of hydrogen sulfide. *Journal of the Air & Waste Management Association*, 59(12), 1458-1467.

Sen, A., Albarella, J. D., Carey, J. R., Kim, P., & McNamara, W. B. (2008). Low-cost colorimetric sensor for the quantitative detection of gaseous hydrogen sulfide, *Sensors and Actuators, B: Chemical*, 134(1), 234-237.

Sevilla, M., & Fuertes, A. B. (2013). A general and facile synthesis strategy towards highly porous carbons: carbonization of organic salts. *Journal of Materials Chemistry A*, 1(44), 13738-13741.

Seyedin, S., & Hassanzadeganroudsari, M. (2018). Evaluation of the different methods of spent caustic treatment, *International Journal of Advanced Researcg in Science, Engineering and Technology*, 5(2), 5275–5283.

Seyedin, S., & Hassanzadeganroudsari, M. (2018). The efficient process for spent-caustic wastewater treatment, *International Journal of Advanced Research in Science, Engineering and Technology*, 5(2), 5284-5288.

Sharma, N., Tiwari, D. P., & Singh, S. K. (2012). Decolourisation of synthetic dyes by agricultural waste- a review, *International Journal of Scientific & Engineering Research*, 3(2), 1-10.

Shokrollahzadeh, S., Golmohammad, F., Naseri, N., Shokouhi, H., & Arman-Mehr, M. (2012). Chemical oxidation for removal of hydrocarbons from gas-field produced water, *Procedia Engineering*, 42, 942-947.

Singh, R. (2014). Membrane technology and engineering for water purification: application, systems design and operation. Butterworth-Heinemann.

Sipma, J., Svitelskaya, A., Van Der Mark, B., Pol, L. W. H., Lettinga, G., Buisman, C. J. N., & Janssen, A. J. H. (2004). Potentials of biological oxidation processes for the treatment of spent sulfidic caustics containing thiols, *Water Research*, 38(20), 4331–4340.

Sitthikhankaew, R., Chadwick, D., Assabumrungrat, S., & Laosiripojana, N. (2014). Effects of humidity, O_2, and CO_2 on H_2S adsorption onto upgraded and KOH impregnated activated carbons, *Fuel Processing Technology*, 124, 249–257.

Skrtic, L. (2006). Hydrogen sulfide, oil and gas, and people's health, *Energy*, 1–77.

Soji Adeyinka, J., & Rim-Rukeh, A. (1999). Effect of hydrogen peroxide on industrial waste water effluents: a case study of Warri refining and petrochemical industry, *Environmental Monitoring and Assessment*, 59(3), 249-256.

Solvay Interox. (2001). Hydrogen peroxide controlling reduced sulphur compounds, 1–9.

Tan, I. A. W., Hameed, B. H., & Ahmad, A. L. (2007). Equilibrium and kinetic studies on basic dye adsorption by oil palm fibre activated carbon, *Chemical Engineering Journal*, 127(1-3), 111-119.

Terzyk, A. P. (2004). Molecular properties and intermolecular forces — factors balancing the effect of carbon surface chemistry in adsorption of organics from dilute aqueous solutions, *Journal of Colloid and Interface Science*, 275(1), 9-29.

Thompson, M. A., Kelkar, U. G., & Vickers, J. C. (1995). The treatment of groundwater containing hydrogen sulfide using microfiltration, *Desalination*, 102(1-3), 287-291.

Tsang, Y. F., Wang, L., & Chua, H. (2015). Simultaneous hydrogen sulphide and ammonia removal in a biotrickling filter: crossed inhibitory effects among selected pollutants and microbial community change, *Chemical Engineering Journal*, 281, 389-396.

Tumin, N. D., Chuah, A. L., Zawani, Z., & Rashid, S. A. (2008). Adsorption of copper from aqueous solution by Elais Guineensis kernel activated carbon, *Journal of Engineering Science and Technology*, 3(2), 180-189.

Tzvi, Y., & Paz, Y. (2019). Highly efficient method for oxidation of dissolved hydrogen sulfide in water, utilizing a combination of UVC light and dissolved oxygen, *Journal of Photochemistry & Photobiology A: Chemistry*, 372, 63-70.

US Environmental Protection Agency. (1991). Hydrogen Sulphide Corrosion in Waste water Collection and Treatment System. *US Environmental Protection Agency*.

US Environmental Protection Agency. (1999). Wastewater Technology Fact Sheet Ozone Disinfection. *US Environmental Protection Agency*.

Vaiopoulou, E., Provijn, T., Prévoteau, A., Pikaar, I., & Rabaey, K. (2016). Electrochemical sulfide removal and caustic recovery from spent caustic streams, *Water research*, 92, 38-43.

Vaiopoulou, E., Melidis, P., & Aivasidis, A. (2005). Sulfide removal in wastewater from petrochemical industries by autotrophic denitrification, *Water Research*, 39(17), 4101-4109.

Vollertsen, J., Nielsen, A. H., Jensen, H. S., Wium-Andersen, T., & Hvitved-Jacobsen, T. (2008). Corrosion of concrete sewers-the kinetics of hydrogen sulfide oxidation, *Science of the Total Environment*, 394(1), 162-170.

Wahi, R., Ngaini, Z., & Jok, V. U. (2009). Removal of mercury, lead and copper from aqueous solution by activated carbon of palm oil empty fruit bunch, *World Applied Science Journal*, 5(84), 84-91.

Wei, O. C. (2008). Preparation and evaluation of mangrove tannins-based adsorbent for the removal of heavy metal ions from aqueous solution. PhD Thesis. University Sains Malaysia, Malaysia.

Wiemann, M., Schenk, H., & Hegemann, W. (1998). Anaerobic treatment of tannery wastewater with simultaneous sulphide elimination, *Water Research*, 32(3), 774-780.

Xiao, Y., Wang, S., Wu, D., & Yuan, Q. (2008). Experimental and simulation study of hydrogen sulfide adsorption on impregnated activated carbon under anaerobic conditions, *Journal of Hazardous Materials*, 153(3), 1193-1200.

Yii Siang, H., Mohd Tahir, N., Malek, A., & Md Isa, M. A. (2017). Breakdown of hydrogen sulfide in seawater under different ratio of dissolved oxygen/hydrogen sulfide, *Malaysian Journal of Analytical Sciences*, 21(5), 1016-1027.

Zhang, S., Shao, T., & Karanfil, T. (2011). The effects of dissolved natural organic matter on the adsorption of synthetic organic chemicals by activated carbons and carbon nanotubes, *Water Research*, 45(3), 1378-1386.

Zhang, X., Li, A., Jiang, Z., & Zhang, Q. (2006). Adsorption of dyes and phenol from water on resin adsorbents : effect of adsorbate size and pore size distribution, *Journal of hazardous materials*, 137(2), 1115-1122.

Zhang, Y., & Pagilla, K. R. (2013). Gas-phase ozone oxidation of hydrogen sulfide for odor treatment in water reclamation plants, *Ozone: Science & Engineering*, 35(5), 390-398.

Zhou, L. (2005). Progress in fundamental research into supercritical adsorption and its impact on clean energy technology, *Adsorption Science & Technology*, 23(7), 509-518.