STUDI KINETIKA, MEKANISME, DAN EFESIENSI ADSORPSI PEWARNA INDIGO CARMINE DARI AIR LIMBAH MENGGUNAKAN BIOCHAR BERBASIS LIMBAH BIOMASA BIJI ASAM JAWA

TESIS

diajukan untuk memenuhi salah satu syarat memperoleh gelar Magister Sains di bidang Kimia

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PROGRAM STUDI MAGISTER KIMIA

FAKULTAS PENDIDIKAN MATEMATIKA DAN ILMU PENGETAHUAN ALAM

UNIVERSITAS PENDIDIKAN INDONESIA

2023

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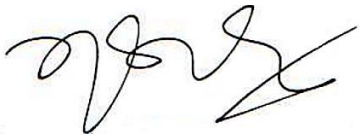

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PERNYATAAN

Dengan ini saya menyatakan bahwa tesis dengan judul "**STUDI KINETIKA, MEKANISME, DAN EFESIENSI ADSORPSI PEWARNA INDIGO CARMINE DARI AIR LIMBAH MENGGUNAKAN BIOCHAR BERBASIS LIMBAH BIOMASA BIJI ASAM JAWA**" ini beserta seluruh isinya adalah benar-benar karya saya sendiri. Saya tidak melakukan penjiplakan atau pengutipan dengan cara-cara yang tidak sesuai dengan etika ilmu yang berlaku dalam masyarakat keilmuan. Atas pernyataan ini, saya siap menanggung resiko/sanksi apabila dikemudian hari ditemukan adanya pelanggaran etika keilmuan atau ada klaim dari pihak lain terhadap keaslian karya saya ini.

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KATA PENGANTAR

Dengan memanjatkan puji dan syukur ke hadirat Allah SWT Yang Maha Pengasih lagi Maha Penyayang, penulis dapat menyelesaikan tesis yang berjudul "**STUDI KINETIKA, MEKANISME, DAN EFESIENSI ADSORPSI PEWARNA INDIGO CARMINE DARI AIR LIMBAH MENGGUNAKAN BIOCHAR BERBASIS LIMBAH BIOMASA BIJI ASAM JAWA** ". Tesis ini disusun sebagai salah satu syarat untuk menempuh ujian magister sains. Tesis ini merupakan hasil penelitian yang mengemukakan masalah penelitian, metode penelitian, analisis data, dan teori pendukung yang dikemukakan dengan merujuk pendapat para ahli.

Penulis menyadari banyak kekurangan dalam penullisan tesis ini sehingga dengan kerendahan hati penulis berharap adanya kritik dan saran untuk perbaikan dalam penelitian ini. Akhir kata semoga tesis ini dapat bermanfaat bagi kita semua.

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UCAPAN TERIMAKASIH

Segala puji dan syukur ke hadirat Allah SWT penuli haturkan karena berkat rahmat dan anugerah-Nya, akhirnya penulis telah telah berhasil menyelesaikan tesis yang berjudul "**STUDI KINETIKA, MEKANISME, DAN EFESIENSI ADSORPSI PEWARNA INDIGO CARMINE DARI AIR LIMBAH MENGGUNAKAN BIOCHAR BERBASIS LIMBAH BIOMASA BIJI ASAM JAWA**".

Tesis ini disusun untuk memenuhi salah satu syarat guna menempuh ujian Magister Sains. Peneliti menyadari bahwa tanpa adanya dukungan dari berbagai pihak, penyusunan tesis ini tidak akan pernah terwujud. Maka pada kesempatan ini, peneliti ingin menyampaikan banyak terima kasih kepada berbagai pihak, diantaranya:

1. Bapak Dr.Eng. Asep Bayu Dani Nandiyanto, S.T., M.Eng, selaku pembimbing I atas bimbingannya baik di bidang akademik maupun non akademik, atas dukungannya berupa materiil maupun moriil, dan atas motivasi, saran, arahan, dan nasihat yang telah diberikan kepada penulis dengan sabar dan penuh perhatian selama menjalankan perkuliahan.
2. Bapak Dr.rer.nat Ahmad Mudzakir, M.Si., selaku pembimbing II yang telah membantu dan memberikan bimbingan serta dukungan selama menjalankan perkuliahan.
3. Ibu Prof. Fitri Khoerunisa, Ph.D dan Bapak Dr. Budiman Anwar, M.Si selaku penguji yang telah memberikan saran, masukan, dan arahan yang sangat luar biasa selama pengerjaan tesis.
4. Bapak dan Ibu dosen program studi Magister Kimia yang telah memberikan ilmunya, pengalaman, dan membimbing selama perkuliahan.
5. Bapak dan Ibu staff tata usaha dan laboran yang telah banyak membantu dalam segala urusan administrasi, birokrasi, dan proses kelancaran pembelajaran selama perkuliahan.
6. Kedua orang tua tercinta yang selalu memberikan dukungan berupa doa, semangat, dan perhatian serta kasih sayang kepada penulis.
7. Sahabat kuncen university center (Dwi Fitria Alhusaeni, Dwi Novia Alhusaeni, Siti Nur Hofifah, dan Meli Fiandini), sahabat seperjuangan sejak sekolah menengah pertama (Denita Teza Ayu Apriliandita dan Yulia Kartika), serta rekan angkatan (Restiani Alia, Yustika Desti Yolanda, Siti Fatimah, Rauza Tinur, Mia Widyaningsih, Humairah Ansar Tohe, Lilis Sumiati, Hari Agung, dan Karina Mulya Rizky) yang telah membersamai penulis selama menyelesaikan penelitian dan penulisan tesis ini.
8. Serta semua pihak yang telah membantu memberi dukungan dan bantuan yang tidak dapat penulis sebutkan satu persatu.

Akhir kata, penulis sampaikan dan ucapkan terimakasih kepada semua pihak yang telah membantu dan mendukung dalam penyusunan tesis ini. Semoga semua amal baik yang telah diberikan mendapatkan balasan yang lebih baik dari Allah SWT, Aamiin.

Bandung, 20 Februari 2023

Penulis

ABSTRAK

Pewarna sintetik seperti Indigo Carmine (IC) dari limbah cair dapat membahayakan manusia atau lingkungan, bahkan pada konsentrasi rendah. Penelitian ini menyelidiki karakteristik fisikokimia, kinetika adsorpsi, dan mekanisme adsorpsi dari adsorben biochar yang dipreparasi melalui pemanfaatan limbah biji asam jawa dalam mereduksi pewarna dari larutan berair. Biochar disiapkan melalui karbonisasi pada suhu 250°C selama 5 jam dan dikarakterisasi untuk ukuran dan morfologi partikel, gugus fungsi, dan luas permukaan yang masing-masing menggunakan intrumen Scanning Electron Microscope (SEM), spektroskopi Fourier Transform Infrared (FTIR), dan Brunauer-Emmett-Teller (BET). Uji adsorpsi batch dilakukan dengan memvariasikan ukuran partikel biochar berbasis biji asam jawa yang berbeda (500, 1000, dan 2000 µm). Beberapa variabel meliputi ukuran partikel (500, 1000, dan 2000 µm), waktu kontak (5-60 menit), konsentrasi awal IC (40–100 mg/L), massa adsorben (0,1-0.5 g), dan pH awal larutan IC (1, 7, dan 13) juga dipelajari. Parameter kinetika dan isoterm adsorpsi diskemakan dengan metode linear melalui pencocokan data pada 2 model kinetika adsorpsi (seperti pseudo-first-order dan pseudo-second-order) dan pada 4 model isoterm adsorpsi (seperti Langmuir, Freundlich, Temkin, dan Dubinin-Radushkevich). Hasil karaktersasi SEM menunjukkan bahwa bioadsorben biochar memiliki permukaan berpori dengan ukuran partikel tidak homogen untuk semua variasi ukuran partikel. Hasil BET menunjukkan bahwa luas permukaan dari biochar berbasis biji asam jawa meningkat seiring menurunan ukuran partikel dan tipe porinya dikonfirmasi sebagai tipe III. Kemudian, analisis gugus fungsi menunjukkan keberadaan hidroksil, alkil, alkena, karbonil, karbon-heteroatom (C-N). Berdasarkan hasil karakterisasi fisikokimia ini, biochar dari biji asam jawa berhasil dipreparasi. Hasil eksperimen menunjukkan bahwa persentase penghilangan pewarna IC meningkat seiring penurunan ukuran partikel adsorben, kenaikan waktu kontak adsorpsi, kenaikan massa adsorben, dan penurunan pH. Namun, persentasi penghilangan pewarna IC ini menurun seiring dengan peningkatan konsentrasi awal larutan adsorbat. Karakteristik adsorpsi IC menunjukkan bahwa adsorpsi mengikuti model Freundlih untuk adsorben biochar berukuran 500 µm dan mengikuti model Dubinin-Radushkevich untuk biochar berukuran 1000 dan 2000 µm. Kemudian, model kinetika orde dua semu adalah model terbaik yang dapat diterapkan untuk menggambarkan kinetika adsorpsi untuk seluruh jenis ukuran partikel adsorben. Penelitian menunjukkan bahwa limbah agro yang digunakan dalam penelitian ini adalah prekursor yang memungkinkan untuk memproduksi adsorben secara lokal dengan biaya rendah. Namun, agar mencapai efesiensi adsorpsi yang baik, perlu adanya modifikasi permukaan pada adsorben biochar jenis ini.

Kata Kunci: Biji Asam Jawa, Bioadsorben, Isoterm Adsorpsi, Kinetika Adsorpsi, Pewarna Indigo Carmine (IC).

ABSTRACT

Synthetic dyes such as Indigo Carmine (IC) from wastewater can be harmful to humans or the environment, even at low concentrations. This study investigated the physicochemical characteristics, adsorption kinetics, and adsorption mechanism of biochar adsorbents prepared by utilizing tamarind seed waste in reducing dyes from aqueous solutions. Biochar was prepared by carbonization at 250°C for 5 hours and characterized for particle size and morphology, functional groups, and surface area respectively using Scanning Electron Microscope (SEM), Fourier Transform Infrared (FTIR) spectroscopy, and Brunauer- Emmett-Teller (BET). Batch adsorption tests were carried out by varying the particle sizes of different tamarind seed-based biochar (500, 1000, and 2000 µm). Several variables include particle size (500, 1000, and 2000 µm), contact time (5-60 minutes), initial concentration of IC (40–100 mg/L), mass of adsorbent (0.1-0.5 g), and initial pH IC solutions (1, 7, and 13) were also studied. Parameters of adsorption kinetics and isotherms were schematized using the linear method by matching data to 2 adsorption kinetics models (such as pseudo-first-order and pseudo-second-order) and to 4 adsorption isotherm models (such as Langmuir, Freundlich, Temkin, and Dubinin-Radushkevich) . SEM characterization results show that the biochar bioadsorbent has a porous surface with inhomogeneous particle sizes for all variations in particle size. BET results showed that the surface area of tamarind seed-based biochar increased with decreasing particle size and the pore type was confirmed as type III. Then, functional group analysis showed the presence of hydroxyl, alkyl, alkene, carbonyl, carbon-heteroatom (C-N). Based on the results of this physicochemical characterization, biochar from tamarind seeds was successfully prepared. The experimental results showed that the percentage of IC dye removal increased as the adsorbent particle size decreased, the adsorption contact time increased, the adsorbent mass increased, and the pH decreased. However, the percentage of IC dye removal decreased with increasing the initial concentration of the adsorbate solution. The IC adsorption characteristics showed that adsorption followed the Freundlih model for 500 µm biochar adsorbents and followed the Dubinin-Radushkevich model for 1000 and 2000 µm biochar. Then, the pseudo second order kinetic model is the best model that can be applied to describe the adsorption kinetics for all types of adsorbent particle sizes. The research shows that the agro-waste used in this study is a precursor that makes it possible to produce adsorbents locally at low cost. However, in order to achieve good adsorption efficiency, it is necessary to modify the surface of this type of biochar adsorbent.

Keyword: Adsorption isotherm, Bioadsorbent, Indigo Carmine (IC) Dye, Kinetic Adsorption, Tamarind Seed.

DAFTAR ISI

Daftar Isi

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DAFTAR PUSTAKA

Abd Mutalib, M., Rahman, M. A., Othman, M. H. D., Ismail, A. F., & Jaafar, J. (2017). Scanning electron microscopy (SEM) and energy-dispersive X-ray (EDX) spectroscopy. In Membrane characterization (pp. 161-179). Elsevier.

Ahlawat, W., Kataria, N., Dilbaghi, N., Hassan, A. A., Kumar, S., & Kim, K. H. (2020). Carbonaceous nanomaterials as effective and efficient platforms for removal of dyes from aqueous systems. Environmental research, 181, 108904.

Ahmad, M. A., Ahmad, N., & Bello, O. S. (2015). Modified durian seed as adsorbent for the removal of methyl red dye from aqueous solutions. Applied Water Science, 5, 407-423.

Alcañiz-Monge, J., Linares-Solano, A., & Rand, B. (2002). Mechanism of adsorption of water in carbon micropores as revealed by a study of activated carbon fibers. The Journal of Physical Chemistry B, 106(12), 3209-3216.

Al-Gheethi, A. A., Azhar, Q. M., Kumar, P. S., Yusuf, A. A., Al-Buriahi, A. K., Mohamed, R. M. S. R., & Al-Shaibani, M. M. (2022). Sustainable approaches for removing Rhodamine B dye using agricultural waste adsorbents: A review. Chemosphere, 287, 132080.

Al-Ghouti, M. A., Al-Kaabi, M. A., Ashfaq, M. Y., & Da'na, D. A. (2019). Produced water characteristics, treatment and reuse: A review. Journal of Water Process Engineering, 28, 222-239.

Alharbi, H. A., Hameed, B. H., Alotaibi, K. D., Al-Oud, S. S., & Al-Modaihsh, A. S. (2022). Recent methods in the production of activated carbon from date palm residues for the adsorption of textile dyes: A review. Frontiers in Environmental Science, 10, 996953.

Ali, R. M., Hamad, H. A., Hussein, M. M., & Malash, G. F. (2016). Potential of using green adsorbent of heavy metal removal from aqueous solutions: adsorption kinetics, isotherm, thermodynamic, mechanism and economic analysis. Ecological Engineering, 91, 317-332.

Ambroz, F., Macdonald, T. J., Martis, V., & Parkin, I. P. (2018). Evaluation of the BET Theory for the Characterization of Meso and Microporous MOFs. Small methods, 2(11), 1800173.

Amen, R., Yaseen, M., Mukhtar, A., Klemeš, J. J., Saqib, S., Ullah, S., ... & Bokhari, A. (2020). Lead and cadmium removal from wastewater using eco-friendly biochar adsorbent derived from rice husk, wheat straw, and corncob. Cleaner Engineering and Technology, 1, 100006.

Anabtawi, F., Mahmoud, N., Al-Khatib, I. A., & Hung, Y. T. (2022). Heavy metals in harvested rainwater used for domestic purposes in rural areas: Yatta Area, Palestine as a case study. International Journal of Environmental Research and Public Health, 19(5), 2683.

Awogbemi, O., & Von Kallon, D. V. (2022). Pretreatment techniques for agricultural waste. Case Studies in Chemical and Environmental Engineering, 100229.

Beksissa, R., Tekola, B., Ayala, T., & Dame, B. (2021). Investigation of the adsorption performance of acid treated lignite coal for Cr (VI) removal from aqueous solution. Environmental Challenges, 4, 100091.

Ben Nasr, J., & Ghorbal, A. (2021). Adsorption of Indigo Carmine dye onto physicochemical-activated leaves of Agave Americana L. Iranian Journal of Chemistry and Chemical Engineering, 40(4), 1054-1066.

Bensalah, H., Younssi, S. A., Ouammou, M., Gurlo, A., & Bekheet, M. F. (2020). Azo dye adsorption on an industrial waste-transformed hydroxyapatite adsorbent: Kinetics, isotherms, mechanism and regeneration studies. Journal of environmental chemical engineering, 8(3), 103807.

Bharti, V., Vikrant, K., Goswami, M., Tiwari, H., Sonwani, R. K., Lee, J., ... & Singh, R. S. (2019). Biodegradation of methylene blue dye in a batch and continuous mode using biochar as packing media. Environmental research, 171, 356-364.

Biswas, J. K., Mondal, B., Priyadarshini, P., Abhilash, P. C., Biswas, S., & Bhatnagar, A. (2022). Formulation of Water Sustainability Index for India as a performance gauge for realizing the United Nations Sustainable Development Goal 6. Ambio, 51(6), 1569-1587.

Boni, M. R., Chiavola, A., & Marzeddu, S. (2020). Remediation of lead-contaminated water by virgin coniferous wood biochar adsorbent: Batch and column application. Water, Air, & Soil Pollution, 231, 1-16.

Bordoloi, N., Dey, M. D., Mukhopadhyay, R., & Kataki, R. (2018). Adsorption of Methylene blue and Rhodamine B by using biochar derived from Pongamia glabra seed cover. Water Science and Technology, 77(3), 638-646.

Castillo-Suárez, L. A., Sierra-Sánchez, A. G., Linares-Hernández, I., Martínez-Miranda, V., & Teutli-Sequeira, E. A. (2023). A critical review of textile industry wastewater: green technologies for the removal of indigo dyes. International Journal of Environmental Science and Technology, 1-38.

Centres, P. M., Bulnes, F., Riccardo, J. L., Ramirez-Pastor, A. J., & Perarnau, M. A. (2011). Adsorption on Heterogeneous Surfaces with Simple Topographies. Adsorption Science & Technology, 29(7), 613-627.

Che, M., & Védrine, J. C. (Eds.). (2012). Characterization of solid materials and heterogeneous catalysts: From structure to surface reactivity. John Wiley & Sons.

Chen, H., Wang, X., Li, J., & Wang, X. (2015). Cotton derived carbonaceous aerogels for the efficient removal of organic pollutants and heavy metal ions. Journal of Materials Chemistry A, 3(11), 6073-6081.

Chen, L., Xu, J., & Chen, J. (2015). Applications of scanning electron microscopy in earth sciences. Science China Earth Sciences, 58, 1768-1778.

Cheng, S. Y., Show, P. L., Lau, B. F., Chang, J. S., & Ling, T. C. (2019). New prospects for modified algae in heavy metal adsorption. Trends in biotechnology, 37(11), 1255-1268.

Chilakamarry, C. R., Sakinah, A. M., Zularisam, A. W., Sirohi, R., Khilji, I. A., Ahmad, N., & Pandey, A. (2022). Advances in solid-state fermentation for bioconversion of agricultural wastes to value-added products: Opportunities and challenges. Bioresource technology, 343, 126065.

Chojnacka, K., Gorazda, K., Witek-Krowiak, A., & Moustakas, K. (2019). Recovery of fertilizer nutrients from materials-Contradictions, mistakes and future trends. Renewable and Sustainable Energy Reviews, 110, 485-498.

Choudhary, M., Peter, C. N., Shukla, S. K., Govender, P. P., Joshi, G. M., & Wang, R. (2020). Environmental issues: a challenge for wastewater treatment. Green materials for wastewater treatment, 1-12.

Chowdhury, M. F., Khandaker, S., Sarker, F., Islam, A., Rahman, M. T., & Awual, M. R. (2020). Current treatment technologies and mechanisms for removal of indigo carmine dyes from wastewater: A review. Journal of Molecular Liquids, 318, 114061.

Crittenden, B., & Thomas, W. J. (1998). Adsorption technology and design. Elsevier.

Dai, J., Meng, X., Zhang, Y., & Huang, Y. (2020). Effects of modification and magnetization of rice straw derived biochar on adsorption of tetracycline from water. Bioresource Technology, 311, 123455.

Dawood, S., Sen, T. K., & Phan, C. (2016). Adsorption removal of Methylene Blue (MB) dye from aqueous solution by bio-char prepared from Eucalyptus sheathiana bark: kinetic, equilibrium, mechanism, thermodynamic and process design. Desalination and water treatment, 57(59), 28964-28980.

de Carvalho, T., Fungaro, D., Magdalena, C., & Cunico, P. (2011). Adsorption of indigo carmine from aqueous solution using coal fly ash and zeolite from fly ash. Journal of Radioanalytical and Nuclear Chemistry, 289(2), 617-626.

de Keijzer, M., van Bommel, M. R., Keijzer, R. H. D., Knaller, R., & Oberhumer, E. (2012). Indigo carmine: understanding a problematic blue dye. Studies in Conservation, 57(sup1), S87-S95.

Deng, D., Lamssali, M., Aryal, N., Ofori-Boadu, A., Jha, M. K., & Samuel, R. E. (2020). Textiles wastewater treatment technology: A review. Water Environment Research, 92(10), 1805-1810.

Dutta, A. (2017). Fourier transform infrared spectroscopy. Spectroscopic methods for nanomaterials characterization, 73-93.

Ebifa-Othieno, E., Kabasa, J. D., Nyeko, P., Nakimbugwe, D., & Mugisha, A. (2020). Nutritional potential of tamarind (Tamarindus indica L.) from semi-arid and subhumid zones of Uganda. Journal of Food Measurement and Characterization, 14, 1125-1134.

Eid, M. M. (2022). Characterization of Nanoparticles by FTIR and FTIR-Microscopy. In Handbook of Consumer Nanoproducts (pp. 1-30). Singapore: Springer Singapore.

El-Kammah, M., Elkhatib, E., Gouveia, S., Cameselle, C., & Aboukila, E. (2022). Cost-effective ecofriendly nanoparticles for rapid and efficient indigo carmine dye removal from wastewater: Adsorption equilibrium, kinetics and mechanism. Environmental Technology & Innovation, 28, 102595.

El-Kammah, M., Elkhatib, E., Gouveia, S., Cameselle, C., & Aboukila, E. (2022). Cost-effective ecofriendly nanoparticles for rapid and efficient indigo carmine dye removal from wastewater: Adsorption equilibrium, kinetics and mechanism. Environmental Technology & Innovation, 28, 102595.

Fang, J., Zhan, L., Ok, Y. S., & Gao, B. (2018). Minireview of potential applications of hydrochar derived from hydrothermal carbonization of biomass. Journal of Industrial and Engineering Chemistry, 57, 15-21.

Fiandini, M., Ragadhita, R., Nandiyanto, A. B. D., & Nugraha, W. C. (2020). Adsorption characteristics of submicron porous carbon particles prepared from rice husk. Journal of Engineering Science and Technology, 15(1), 022-31.

Gaffney, J. S., Marley, N. A., & Jones, D. E. (2002). Fourier transform infrared (FTIR) spectroscopy. Characterization of materials, 1-33.

Gao, J., Liu, Y., Li, X., Yang, M., Wang, J., & Chen, Y. (2020). A promising and cost-effective biochar adsorbent derived from jujube pit for the removal of Pb (II) from aqueous solution. Scientific reports, 10(1), 7473.

Gil, A., Santamaría, L., Korili, S. A., Vicente, M. A., Barbosa, L. V., De Souza, S. D., ... & Ciuffi, K. J. (2021). A review of organic-inorganic hybrid clay based adsorbents for contaminants removal: Synthesis, perspectives and applications. Journal of Environmental Chemical Engineering, 9(5), 105808.

Gong, J., Liu, J., Jiang, Z., Wen, X., Mijowska, E., Tang, T., & Chen, X. (2015). A facile approach to prepare porous cup-stacked carbon nanotube with high performance in adsorption of methylene blue. Journal of colloid and interface science, 445, 195-204.

González, M. E., Cea, M., Reyes, D., Romero-Hermoso, L., Hidalgo, P., Meier, S., ... & Navia, R. (2017). Functionalization of biochar derived from lignocellulosic biomass using microwave technology for catalytic application in biodiesel production. Energy conversion and management, 137, 165-173.

Goodman, B. A. (2020). Utilization of waste straw and husks from rice production: A review. Journal of Bioresources and Bioproducts, 5(3), 143-162.

Guo, H., Bi, C., Zeng, C., Ma, W., Yan, L., Li, K., & Wei, K. (2018). Camellia oleifera seed shell carbon as an efficient renewable bio-adsorbent for the adsorption removal of hexavalent chromium and methylene blue from aqueous solution. Journal of molecular liquids, 249, 629-636.

Gupta, T., Ansari, K., Lataye, D., Kadu, M., Khan, M. A., Mubarak, N. M., ... & Karri, R. R. (2022). Adsorption of Indigo Carmine Dye by Acacia nilotica sawdust activated carbon in fixed bed column. Scientific Reports, 12(1), 15522.

Harrache, Z., Abbas, M., Aksil, T., & Trari, M. (2019). Thermodynamic and kinetics studies on adsorption of Indigo Carmine from aqueous solution by activated carbon. Microchemical Journal, 144, 180-189.

Hevira, L., Ighalo, J. O., & Zein, R. (2020). Biosorption of indigo carmine from aqueous solution by Terminalia catappa shell. Journal of Environmental Chemical Engineering, 8(5), 104290.

Hevira, L., Ighalo, J. O., & Zein, R. (2020). Biosorption of indigo carmine from aqueous solution by Terminalia catappa shell. Journal of Environmental Chemical Engineering, 8(5), 104290.

Hu, Q., Pang, S., & Wang, D. (2022). In-depth insights into mathematical characteristics, selection criteria and common mistakes of adsorption kinetic models: a critical review. Separation & Purification Reviews, 51(3), 281-299.

Huang, J. (2010). Molecular sieving effect of a novel hyper-cross-linked resin. Chemical Engineering Journal, 165(1), 265-272.

Hung, N. V., Nguyet, B. T. M., Nghi, N. H., Thanh, N. M., Quyen, N. D. V., Nguyen, V. T., ... & Khieu, D. Q. (2022). Highly effective adsorption of organic dyes from aqueous solutions on longan seed-derived activated carbon. Environmental Engineering Research, 28(3), 220116.

Huong, D. T. M., Chai, W. S., Show, P. L., Lin, Y. L., Chiu, C. Y., Tsai, S. L., & Chang, Y. K. (2020). Removal of cationic dye waste by nanofiber membrane immobilized with waste proteins. International Journal of Biological Macromolecules, 164, 3873–3884. https://doi.org/10.1016/j.ijbiomac.2020.09.020

Huong, P. T., Jitae, K., Al Tahtamouni, T. M., Tri, N. L. M., Kim, H. H., Cho, K. H., & Lee, C. (2020). Novel activation of peroxymonosulfate by biochar derived from rice husk toward oxidation of organic contaminants in wastewater. Journal of Water Process Engineering, 33, 101037.

Ibrahim, W. M. (2011). Biosorption of heavy metal ions from aqueous solution by red macroalgae. Journal of Hazardous Materials, 192(3), 1827-1835.

Inkson, B. J. (2016). Scanning electron microscopy (SEM) and transmission electron microscopy (TEM) for materials characterization. In Materials characterization using nondestructive evaluation (NDE) methods (pp. 17-43). Woodhead publishing.

Iqbal, N., Agrawal, A., Dubey, S., & Kumar, J. (2020). Role of decomposers in agricultural waste management. In Biotechnological Applications of Biomass. IntechOpen.

Isam, M., Baloo, L., Kutty, S. R. M., & Yavari, S. (2019). Optimisation and modelling of Pb (II) and Cu (II) biosorption onto red algae (Gracilaria changii) by using response surface methodology. Water, 11(11), 2325.

Ishak, Z., & Kumar, D. (2022). Adsorption of methylene blue and reactive black 5 by activated carbon derived from tamarind seeds. Tropical Aquatic and Soil Pollution, 2(1), 1-12.

Jalali, R., Ghafourian, H., Asef, Y., Davarpanah, S. J., & Sepehr, S. (2002). Removal and recovery of lead using nonliving biomass of marine algae. Journal of Hazardous Materials, 92(3), 253-262.

Jiménez de Cisneros, C., Peña, A., Caballero, E., & Liñán, C. (2021). A multiparametric approach for evaluating the current carbonate precipitation and external soil of Nerja Cave (Málaga, Spain). International Journal of Environmental Research, 15, 231-243.

Kamdod, A. S., & Kumar, M. V. P. (2022). Adsorption of Methylene blue and Methyl orange on tamarind seed activated carbon and its composite with chitosan: equilibrium and kinetic studies. Desalin Water Treat, 252, 408-419.

Kan, Y., Yue, Q., Li, D., Wu, Y., & Gao, B. (2017). Preparation and characterization of activated carbons from waste tea by H3PO4 activation in different atmospheres for oxytetracycline removal. Journal of the Taiwan Institute of Chemical Engineers, 71, 494-500.

Kekes, T., & Tzia, C. (2020). Adsorption of indigo carmine on functional chitosan and β-cyclodextrin/chitosan beads: Equilibrium, kinetics and mechanism studies. Journal of environmental management, 262, 110372.

Khadhri, N., Saad, M. E. K., ben Mosbah, M., & Moussaoui, Y. (2019). Batch and continuous column adsorption of indigo carmine onto activated carbon derived from date palm petiole. Journal of Environmental Chemical Engineering, 7(1), 102775.

Khan, S. A., Khan, S. B., Khan, L. U., Farooq, A., Akhtar, K., & Asiri, A. M. (2018). Fourier transform infrared spectroscopy: fundamentals and application in functional groups and nanomaterials characterization. Handbook of materials characterization, 317-344.

Koul, B., Yakoob, M., & Shah, M. P. (2022). Agricultural waste management strategies for environmental sustainability. Environmental Research, 206, 112285.

Koul, B., Yakoob, M., & Shah, M. P. (2022). Agricultural waste management strategies for environmental sustainability. Environmental Research, 206, 112285.

Krishnan, S., Zulkapli, N. S., Kamyab, H., Taib, S. M., Din, M. F. B. M., Abd Majid, Z., ... & Othman, N. (2021). Current technologies for recovery of metals from industrial wastes: An overview. Environmental Technology & Innovation, 22, 101525.

Kuang, Y., Zhang, X., & Zhou, S. (2020). Adsorption of methylene blue in water onto activated carbon by surfactant modification. Water, 12(2), 587.

Kumar, R., & Barakat, M. A. (2013). Decolourization of hazardous brilliant green from aqueous solution using binary oxidized cactus fruit peel. Chemical engineering journal, 226, 377-383.

Kumar, R., Verma, A., Shome, A., Sinha, R., Sinha, S., Jha, P. K., ... & Vara Prasad, P. V. (2021). Impacts of plastic pollution on ecosystem services, sustainable development goals, and need to focus on circular economy and policy interventions. Sustainability, 13(17), 9963.

Lakshmi, U. R., Srivastava, V. C., Mall, I. D., & Lataye, D. H. (2009). Rice husk ash as an effective adsorbent: Evaluation of adsorptive characteristics for Indigo Carmine dye. Journal of Environmental Management, 90(2), 710-720.

Li, J., Wang, S. L., Zhang, J., Zheng, L., Chen, D., Wu, Z., ... & Wu, W. (2020). Coconut-fiber biochar reduced the bioavailability of lead but increased its translocation rate in rice plants: Elucidation of immobilization mechanisms and significance of iron plaque barrier on roots using spectroscopic techniques. Journal of hazardous materials, 389, 122117.

Li, M., Wang, H., Wu, S., Li, F., & Zhi, P. (2012). Adsorption of hazardous dyes indigo carmine and acid red on nanofiber membranes. RSC advances, 2(3), 900-907.

Li, Q., Zhai, J., Zhang, W., Wang, M., & Zhou, J. (2007). Kinetic studies of adsorption of Pb (II), Cr (III) and Cu (II) from aqueous solution by sawdust and modified peanut husk. Journal of hazardous materials, 141(1), 163-167.

Lian, F., Cui, G., Liu, Z., Duo, L., Zhang, G., & Xing, B. (2016). One-step synthesis of a novel N-doped microporous biochar derived from crop straws with high dye adsorption capacity. Journal of Environmental Management, 176, 61-68.

Lim, S., Kim, J. H., Park, H., Kwak, C., Yang, J., Kim, J., ... & Lee, J. (2021). Role of electrostatic interactions in the adsorption of dye molecules by Ti 3 C 2-MXenes. RSC advances, 11(11), 6201-6211.

Liu, Q., Zhou, Y., Lu, J., & Zhou, Y. (2020). Novel cyclodextrin-based adsorbents for removing pollutants from wastewater: A critical review. Chemosphere, 241, 125043.

Liu, S., Li, J., Xu, S., Wang, M., Zhang, Y., & Xue, X. (2019). A modified method for enhancing adsorption capability of banana pseudostem biochar towards methylene blue at low temperature. Bioresource technology, 282, 48-55.

Liu, W., Zhang, Y., Wang, S., Bai, L., Deng, Y., & Tao, J. (2021). Effect of pore size distribution and amination on adsorption capacities of polymeric adsorbents. Molecules, 26(17), 5267.

Liu, X., He, C., Yu, X., Bai, Y., Ye, L., Wang, B., & Zhang, L. (2018). Net-like porous activated carbon materials from shrimp shell by solution-processed carbonization and H3PO4 activation for methylene blue adsorption. Powder Technology, 326, 181-189.

Long, C., Lu, J., Li, A., Hu, D., Liu, F., & Zhang, Q. (2008). Adsorption of naphthalene onto the carbon adsorbent from waste ion exchange resin: Equilibrium and kinetic characteristics. Journal of Hazardous Materials, 150(3), 656-661.

Lowell, S., & Shields, J. E. (1991). Powder surface area and porosity (Vol. 2). Springer Science & Business Media.

Luo, Q., Ren, T., Shen, H., Liang, D., & Zhang, J. (2017). Comparison of thermal hazards of sodium dithionite and thiourea dioxide from thermal analysis (DSC-TG), small-scale self-heating experiments and FTIR smoke gas analysis. Fire Safety Journal, 92, 91-97

Ly, J., Sjofjan, O., DJUNAIDI, I. H., & SUYADI, S. (2017). Effect of processing methods on nutrient and tannin content of tamarind seeds. International Journal of Tropical Drylands, 1(2), 78-82.

Lynch, J., Cain, M., Frame, D., & Pierrehumbert, R. (2021). Agriculture's contribution to climate change and role in mitigation is distinct from predominantly fossil CO2-emitting sectors. Frontiers in sustainable food systems, 300.

Ma, J., Zhao, J., Zhu, Z., Li, L., & Yu, F. (2019). Effect of microplastic size on the adsorption behavior and mechanism of triclosan on polyvinyl chloride. Environmental Pollution, 254, 113104.

Mahajani, K. (2020). Physicochemical, functional properties and proximate composition of tamarind seed: Proximate composition of tamarind seed. Journal of AgriSearch, 7(1), 51-53.

Mahanty, B., & Mondal, S. (2021). Synthesis of magnetic biochar using agricultural waste for the separation of Cr (VI) from aqueous solution. Arabian Journal for Science and Engineering, 1-16.

Mahmoud, M. E., Nabil, G. M., El-Mallah, N. M., Bassiouny, H. I., Kumar, S., & Abdel-Fattah, T. M. (2016). Kinetics, isotherm, and thermodynamic studies of the adsorption of reactive red 195 A dye from water by modified Switchgrass Biochar adsorbent. Journal of Industrial and Engineering Chemistry, 37, 156-167.

Mashkoor, F., & Nasar, A. (2020). Magnetized Tectona grandis sawdust as a novel adsorbent: preparation, characterization, and utilization for the removal of methylene blue from aqueous solution. Cellulose, 27(5), 2613-2635.

Matta, G., Kumar, P., Uniyal, D. P., & Joshi, D. U. (2022). Communicating water, sanitation, and hygiene under sustainable development goals 3, 4, and 6 as the panacea for epidemics and pandemics referencing the succession of COVID-19 surges. Acs Es&t Water, 2(5), 667-689.

Mishra, R. K., Zachariah, A. K., & Thomas, S. (2017). Energy-dispersive X-ray spectroscopy techniques for nanomaterial. In Microscopy methods in nanomaterials characterization (pp. 383-405). Elsevier.

Mohammadi, N., Khani, H., Gupta, V. K., Amereh, E., & Agarwal, S. (2011). Adsorption process of methyl orange dye onto mesoporous carbon material–kinetic and thermodynamic studies. Journal of colloid and interface science, 362(2), 457-462.

Musah, M., Azeh, Y., Mathew, J. T., Umar, M. T., Abdulhamid, Z., & Muhammad, A. I. (2022). Adsorption kinetics and isotherm models: a review. CaJoST, 4(1), 20-26.

Musah, M., Mathew, J., Azeh, Y., Badeggi, U., Abdulhamid, Z., & Muhammad, A. (2023). Kinetic studies of the adsorption of manganese (ii) and nickel (ii) ions onto modified oil palm mesocarp fiber. Bima Journal of Science and Technology, (2536-6041), 7(01), 47-53.

Naga Babu A et al (2019) Removal of hazardous indigo carmine dye from waste water using treated red mud. Mater Today: Proc 17:198–208. https://doi.org/10.1016/j.matpr.2019.06.419

Nandiyanto, A. B. D., Arinalhaq, Z. F., Rahmadianti, S., Dewi, M. W., Rizky, Y. P. C., Maulidina, A., ... & Yunas, J. (2020). Curcumin Adsorption on Carbon Microparticles: Synthesis from Soursop (AnnonaMuricata L.) Peel Waste, Adsorption Isotherms and Thermodynamic and Adsorption Mechanism. International Journal of Nanoelectronics & Materials, 13.

Nandiyanto, A. B. D., Azizah, N. N., & Rahmadianti, S. (2021). Isotherm study of banana stem waste adsorbents to reduce the concentration of textile dying waste. Journal of Engineering Research.

Nandiyanto, A. B. D., Oktiani, R., & Ragadhita, R. (2019). How to read and interpret FTIR spectroscope of organic material. Indonesian Journal of Science and Technology, 4(1), 97-118.

Nandiyanto, A. B. D., Oktiani, R., & Ragadhita, R. (2019). How to read and interpret FTIR spectroscope of organic material. Indonesian Journal of Science and Technology, 4(1), 97-118.

Nasrollahi, N., Ghalamchi, L., Vatanpour, V., & Khataee, A. (2021). Photocatalytic-membrane technology: a critical review for membrane fouling mitigation. Journal of Industrial and Engineering Chemistry, 93, 101-116.

Nasrullah, A., Khan, H., Khan, A. S., Man, Z., Muhammad, N., Khan, M. I., ... & Naser, M. (2015). Potential biosorbent derived from Calligonum polygonoides for removal of methylene blue dye from aqueous solution. The Scientific World Journal, 2015.

Niu, Z., Ng, S. J., Li, B., Han, J., Wu, X., & Huang, Y. (2022). Food waste and its embedded resources loss: A provincial level analysis of China. Science of The Total Environment, 823, 153665.

Nworie, F. S., Nwabue, F. I., Oti, W., Mbam, E. 1., & Nwali, B. U. (2019). Removal of methylene blue from aqueous solution using activated rice husk biochar: Adsorption isotherms, kinetics and error analysis. Journal of the Chilean chemical society, 64(1), 4365-4376.

Obey, G., Adelaide, M., & Ramaraj, R. (2022). Biochar derived from non-customized matamba fruit shell as an adsorbent for wastewater treatment. Journal of Bioresources and Bioproducts, 7(2), 109-115.

Ogbaga, C. C., Maishanu, R. A., & Okolo, D. (2019, December). Characterisation of the Rubisco content and bioactive compound analysis of leaf and seed extracts of Tamarindus indica. In 2019 15th International Conference on Electronics, Computer and Computation (ICECCO) (pp. 1-6). IEEE.

Pal, D., & Mukherjee, S. (2020). Tamarind (Tamarindus indica) seeds in health and nutrition. In Nuts and seeds in health and disease prevention (pp. 171-182). Academic Press.

Ramesh, B., Saravanan, A., Kumar, P. S., Yaashikaa, P. R., Thamarai, P., Shaji, A., & Rangasamy, G. (2023). A review on algae biosorption for the removal of hazardous pollutants from wastewater: Limiting factors, prospects and recommendations. Environmental Pollution, 121572.

Ramesh, T. N., Kirana, D. V., Ashwini, A., & Manasa, T. R. (2017). Calcium hydroxide as low cost adsorbent for the effective removal of indigo carmine dye in water. Journal of Saudi Chemical Society, 21(2), 165-171.

Raninga, M., Mudgal, A., Patel, V. K., Patel, J., & Sinha, M. K. (2023). Modification of activated carbon-based adsorbent for removal of industrial dyes and heavy metals: A review. Materials Today: Proceedings, 77, 286-294.

Rashid, R., Shafiq, I., Akhter, P., Iqbal, M. J., & Hussain, M. (2021). A state-of-the-art review on wastewater treatment techniques: the effectiveness of adsorption method. Environmental Science and Pollution Research, 28, 9050-9066.

Rattanapan, S., Srikram, J., & Kongsune, P. (2017). Adsorption of methyl orange on coffee grounds activated carbon. Energy Procedia, 138, 949-954.

Reddy, A. G. K., Osman, M., Yadav, S. K., Prasad, T. V., Shankar, K. S., Pushpanjali, M., ... & Yadagiri, J. (2022). Performance of Tamarind (Tamarindus indica L.) Accessions under Dryland Conditions. Legume Research-An International Journal, 1, 5.

Romera, E., González, F., Ballester, A., Blázquez, M. L., & Munoz, J. A. (2007). Comparative study of biosorption of heavy metals using different types of algae. Bioresource technology, 98(17), 3344-3353.

Saeed, A. A. H., Harun, N. Y., Sufian, S., Siyal, A. A., Zulfiqar, M., Bilad, M. R., ... & Almahbashi, N. (2020). Eucheuma cottonii seaweed-based biochar for adsorption of methylene blue dye. Sustainability, 12(24), 10318.

Sahu, S., Pahi, S., Tripathy, S., Singh, S. K., Behera, A., Sahu, U. K., & Patel, R. K. (2020). Adsorption of methylene blue on chemically modified lychee seed biochar: Dynamic, equilibrium, and thermodynamic study. Journal of Molecular Liquids, 315, 113743.

Samanta, S., Chowdhury, S., DasSharma, D., & Halder, G. (2020). The biosorptive uptake of enrofloxacin from synthetically produced contaminated water by tamarind seed derived activated carbon. RSC advances, 10(2), 1204-1218.

Samsami, S., Mohamadizaniani, M., Sarrafzadeh, M. H., Rene, E. R., & Firoozbahr, M. (2020). Recent advances in the treatment of dye-containing wastewater from textile industries: Overview and perspectives. Process safety and environmental protection, 143, 138-163.

Saxena, G., & Bharagava, R. N. (2017). Organic and inorganic pollutants in industrial wastes: ecotoxicological effects, health hazards, and bioremediation approaches. In Environmental pollutants and their bioremediation approaches (pp. 23-56). CRC Press.

Scimeca, M., Bischetti, S., Lamsira, H. K., Bonfiglio, R., & Bonanno, E. (2018). Energy Dispersive X-ray (EDX) microanalysis: A powerful tool in biomedical research and diagnosis. European journal of histochemistry: EJH, 62(1).

Selvaraj, V., Karthika, T. S., Mansiya, C., & Alagar, M. (2021). An over review on recently developed techniques, mechanisms and intermediate involved in the advanced azo dye degradation for industrial applications. Journal of molecular structure, 1224, 129195.

Shams, R., Singh, J., Pandey, V. K., Dar, A. H., & Singh, P. A Review on Utilization and Bioactive Applications of Tamarind Waste. 1(1), 1-7.

Sharma, P., Kumar, S., & Pandey, A. (2021). Bioremediated techniques for remediation of metal pollutants using metagenomics approaches: a review. Journal of Environmental Chemical Engineering, 9(4), 105684.

Sharma, S. K., Verma, D. S., Khan, L. U., Kumar, S., & Khan, S. B. (Eds.). (2018). Handbook of materials characterization. New York, NY, USA:: Springer International Publishing.

Sonone, S. S., Jadhav, S., Sankhla, M. S., & Kumar, R. (2020). Water contamination by heavy metals and their toxic effect on aquaculture and human health through food Chain. Lett. Appl. NanoBioScience, 10(2), 2148-2166.

Suresh, S., & Sundaramoorthy, S. (2014). Green Chemical Engineering: An introduction to catalysis, kinetics, and chemical processes. CRC Press.

Tabi, G. A., Blaise, L. N. R., Daouda, K., Odogu, A. N., Victoire, A. A., Julius, N. N., & Mbadcam, K. J. (2022). Non-linear modelling of the adsorption of Indigo Carmine dye from wastewater onto characterized activated carbon/volcanic ash composite. Arabian Journal of Chemistry, 15(1), 103515.

Taiwo, A. F., & Chinyere, N. J. (2016). Sorption characteristics for multiple adsorption of heavy metal ions using activated carbon from Nigerian bamboo. Journal of Materials Science and Chemical Engineering, 4(4), 39-48.

Taşar, Ş., Kaya, F., & Özer, A. (2014). Biosorption of lead (II) ions from aqueous solution by peanut shells: Equilibrium, thermodynamic and kinetic studies. Journal of Environmental Chemical Engineering, 2(2), 1018-1026.

Tran, H. N. (2022). Differences between Chemical Reaction Kinetics and Adsorption Kinetics: Fundamentals and Discussion. Journal of Technical Education Science, (70B), 33-47.

Vieira, A. P., Santana, S. A., Bezerra, C. W., Silva, H. A., Chaves, J. A., de Melo, J. C., ... & Airoldi, C. (2009). Kinetics and thermodynamics of textile dye adsorption from aqueous solutions using babassu coconut mesocarp. Journal of Hazardous Materials, 166(2-3), 1272-1278.

Vithanage, M., Mayakaduwa, S. S., Herath, I., Ok, Y. S., & Mohan, D. (2016). Kinetics, thermodynamics and mechanistic studies of carbofuran removal using biochars from tea waste and rice husks. Chemosphere, 150, 781-789.

Vojnović, B., Cetina, M., Franjković, P., & Sutlović, A. (2022). Influence of initial pH value on the adsorption of reactive black 5 dye on powdered activated carbon: Kinetics, mechanisms, and thermodynamics. Molecules, 27(4), 1349.

Volkov, V. V., Chelli, R., Righini, R., & Perry, C. C. (2020). Indigo chromophores and pigments: Structure and dynamics. Dyes and Pigments, 172, 107761.

Walia, R., Chauhan, A., & Kumar, S. (2021). Literature Review On The Elimination Of Fluoride Ions From Industrial Wastewater Utilizing Tamarind. Public Health, 1(2.0), 5.

Wang, S., Boyjoo, Y., Choueib, A., & Zhu, Z. H. (2005). Removal of dyes from aqueous solution using fly ash and red mud. Water research, 39(1), 129-138.

Wang, S., Zhao, M., Zhou, M., Li, Y. C., Wang, J., Gao, B., ... & Ok, Y. S. (2019). Biochar-supported nZVI (nZVI/BC) for contaminant removal from soil and water: a critical review. Journal of Hazardous Materials, 373, 820-834.

Wang, W., Ma, X., Sun, J., Chen, J., Zhang, J., Wang, Y., ... & Zhang, H. (2019). Adsorption of enrofloxacin on acid/alkali-modified corn stalk biochar. Spectroscopy Letters, 52(7), 367-375.

Wekoye, J. N., Wanyonyi, W. C., Wangila, P. T., & Tonui, M. K. (2020). Kinetic and equilibrium studies of Congo red dye adsorption on cabbage waste powder. Environmental Chemistry and Ecotoxicology, 2, 24-31.

Wiśniewska, M., Rejer, K., Pietrzak, R., & Nowicki, P. (2022). Biochars and activated biocarbons prepared via conventional pyrolysis and chemical or physical activation of mugwort herb as potential adsorbents and renewable fuels. Molecules, 27(23), 8597.

Wong, J. K. H., Tan, H. K., Lau, S. Y., Yap, P. S., & Danquah, M. K. (2019). Potential and challenges of enzyme incorporated nanotechnology in dye wastewater treatment: A review. Journal of environmental chemical engineering, 7(4), 103261.

Wu, T., Yang, G., Cao, J., Xu, Z., & Jiang, X. (2022). Activation and adsorption mechanisms of methylene blue removal by porous biochar adsorbent derived from eggshell membrane. Chemical Engineering Research and Design, 188, 330-341.

Xiang, W., Zhang, X., Chen, J., Zou, W., He, F., Hu, X., ... & Gao, B. (2020). Biochar technology in wastewater treatment: A critical review. Chemosphere, 252, 126539.

Xiong, X., Iris, K. M., Tsang, D. C., Bolan, N. S., Ok, Y. S., Igalavithana, A. D., ... & Vikrant, K. (2019). Value-added chemicals from food supply chain wastes: State-of-the-art review and future prospects. Chemical Engineering Journal, 375, 121983.

Xu, R. K., & Zhao, A. Z. (2013). Effect of biochars on adsorption of Cu (II), Pb (II) and Cd (II) by three variable charge soils from southern China. Environmental Science and Pollution Research, 20, 8491-8501.

Yahya, N., Aziz, F., Jamaludin, N. A., Mutalib, M. A., Ismail, A. F., Salleh, W. N. W., ... & Ludin, N. A. (2018). A review of integrated photocatalyst adsorbents for wastewater treatment. Journal of environmental chemical engineering, 6(6), 7411-7425.

Yang, B., Liu, Y., Liang, Q., Chen, M., Ma, L., Li, L., ... & Chen, Y. (2019). Evaluation of activated carbon synthesized by one-stage and two-stage co-pyrolysis from sludge and coconut shell. Ecotoxicology and environmental safety, 170, 722-731.

Yogalakshmi, K. N., Das, A., Rani, G., Jaswal, V., & Randhawa, J. S. (2020). Nano-bioremediation: a new age technology for the treatment of dyes in textile effluents. Bioremediation of Industrial Waste for Environmental Safety: Volume I: Industrial Waste and Its Management, 313-347.

Yu, Y., Wan, Y., Shang, H., Wang, B., Zhang, P., & Feng, Y. (2019). Corncob-to-xylose residue (CCXR) derived porous biochar as an excellent adsorbent to remove organic dyes from wastewater. Surface and Interface Analysis, 51(2), 234-245.

Zhang, J., Zhou, Q., & Ou, L. (2016). Removal of indigo carmine from aqueous solution by microwave-treated activated carbon from peanut shell. Desalination and Water Treatment, 57(2), 718-727.

Zhang, W., Huo, C., Hou, B., Lin, C., Yan, X., Feng, J., & Yan, W. (2021). Secondary particle size determining sedimentation and adsorption kinetics of titanate-based materials for ammonia nitrogen and methylene blue removal. Journal of Molecular Liquids, 343, 117026.