UNIVERSIDAD AUTÓNOMA DE SAN LUIS POTOSÍ
FACULTAD DE CIENCIAS QUÍMICAS

CENTRO DE INVESTIGACIÓN Y ESTUDIOS DE POSGRADO

ADSORCIÓN DE ANIONES DE SELENIO, DICLOFENACO Y OTROS CONTAMINANTES TÓXICOS EN SOLUCIÓN ACUOSA SOBRE DIVERSOS NANOMATERIALES

TESIS QUE PARA OBTENER EL GRADO DE

DOCTOR EN CIENCIAS EN INGENIERÍA QUÍMICA

P R E S E N T A:

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SAN LUIS POTOSÍ, S.L.P., 4 DE MARZO DEL 2022

El programa de Doctorado en Ciencias en Ingeniería Química de la Universidad Autónoma de San Luis Potosí pertenece al Programa Nacional de Posgrados de Calidad (PNPC) del Consejo Nacional de Ciencia y Tecnología (CONACYT), registro 000897 en el Nivel PNPC Consolidado.

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El presente trabajo de Investigación se realizó en el Laboratorio de Ingeniería Química Ambiental perteneciente a la Facultad de Ciencias Químicas de la Universidad Autónoma de San Luis Potosí bajo la asesoría del Dr. Roberto Leyva Ramos. El desarrollo de las espumas bionanocompositos de lignina y sepiolita se realizó en el Instituto de Ciencia de Materiales de Madrid (ICMM) del Consejo Superior de Investigaciones Científicas (CSIC) bajo la tutoría de la Dra. Pilar Aranda y la Dra. Margarita Darder.

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PRESENTA

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Agosto 2022.

Comité Academico
Posgrado en Ciencias en Ingeniería Química
Facultad de Ciencias Químicas
Universidad Autónoma de San Luis Potosí
Presente. -

Estimado Sr. Director,

Por medio de la presente hacemos de su conocimiento que la tesis llevada a cabo por la alumna de Doctorado MCIQ. Brenda Azharel Jiménez López, Titulada:

Adsorción de Aniones de Selenio, Diclofenaco y otros Contaminantes Tóxicos en Solución Acuosa sobre Diversos Nanomateriales

Ha sido concluida y aprobada por el Comité tutorial para iniciar con los trámites correspondientes para su titulación, el cual tendrá lugar el viernes 4 de marzo del presente año a las 17:00 pm. En el Auditorio Chico (G 203)

ATENTAMENTE

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CAPÍTULO 1. INTRODUCCIÓN

El agua es un recurso natural necesario para la vida humana y para el desarrollo de otras actividades cotidianas. La contaminación del agua es la causa de muerte de seres vivos y de enfermedades infecciosas en el ser humano. Según la Organización Mundial de la Salud el 80 % de las enfermedades humanas son transmitidas a través del agua y 3.1 % de las muertes se producen por la falta de calidad del agua (Haseena et al., 2017). Fuentes naturales como erupciones volcánicas, deposición de partículas suspendidas en el aire y erosión de minerales contribuyen levemente a la contaminación del agua; sin embargo, la principal causa de contaminación son las actividades antropogénicas (Ahajad et al, 2020).

La industria, la urbanización, deforestación, residuos de la agricultura y domésticos han afectado la calidad de ríos, lagos, mantos acuíferos y océanos con contaminantes tóxicos. Cerca del 80 % de la contaminación del agua es consecuencia de un mal tratamiento de las aguas residuales domésticas, y la contaminación causada por residuos industriales es la más peligrosa (Das, 2018; Haseena et al., 2017). Los contaminantes del agua se clasifican en ocho principales categorías: Contaminantes orgánicos; inorgánicos (sales y metales); patógenos; nutrientes y escorrentía agrícola; sedimentos y solidos suspendidos; contaminación térmica; contaminantes radioactivos y nanocontaminantes (Ghangrekar y Chatterjee, 2018).

La Agencia de Protección Ambiental de Estados Unidos incluyó a varios metaloides, metales y compuestos orgánicos en la lista de contaminantes prioritarios del agua. Algunos de los metales y metaloides más comúnmente encontrados en agua son As, Be, Cd, Cr, Cu, Pb, Hg, Ni, Se, Ag y Zn (Ahamad et al, 2020). Varios de estos se consideran esenciales para la salud del ser humano; sin embargo, también son no-biodegradables, persistentes y bioacumulables. Una ingesta mayor a la necesaria conduce a serios problemas de salud como cáncer, lesiones intestinales, alergias, daños neurológicos, enfermedades de los huesos, daños a los órganos y problemas en el sistema circulatorio, por mencionar algunos (Ghangrekar y Chatterjee, 2018; Schweitzer y Noblet, 2018). Por otro lado, los fármacos son contaminantes orgánicos, clasificados como contaminantes emergentes debido a que, se presentan de forma continua en aguas superficiales, subterráneas y agua potable en concentraciones entre ng/L y µg/L. Se ha reportado que la estructura de los fármacos en el ambiente acuático se puede modificar y convertir en formas activas, y además, sus efectos nocivos en la salud humana no se conocen hasta el momento (Ahamad et al, 2020).

Varios procesos se aplican para mejorar la calidad del agua; no obstante, la mayoría de las tecnologías son procesos complicados y presentan elevados costos de operación (Das, 2018). Hoy en día, la adsorción se considera un método eficiente, de bajo costo y con simplicidad de diseño; y puede producir efluentes de alta calidad y algunos materiales adsorbentes se pueden regenerar (Burakov et al., 2018). Este proceso es frecuentemente utilizado en las plantas de tratamiento de aguas residuales y plantas potabilizadoras. Además, la adsorción se ha utilizado para la eliminación de contaminantes del agua tales como colorantes, fármacos y metales pesados (De Gisi et al., 2016; Khadir et al., 2020). Diferentes materiales basados en nanoestructuras se han sintetizado y utilizado para la eliminación de contaminantes del agua (Burakov et al., 2018). Los nanomateriales tienen al menos una de sus dimensiones en escala nanométrica. Poseen características únicas que mejoran la capacidad de adsorción y son capaces de adsorber contaminantes con tamaño molecular variable (Santhosh et al., 2016). Los hidróxidos dobles laminares se han utilizado para eliminar compuestos orgánicos e inorgánicos debido a sus sitios básicos, su morfología y propiedad de transformación en óxido metálico (Li et al., 2014). El óxido grafítico es un material a base de grafeno con una gran variedad de grupos funcionales y anillos aromáticos que lo convierten en un adsorbente efectivo para la eliminación de diferentes contaminantes (Santhosh et al., 2016). Por otro lado, biocompositos de arcillas fibrosas son considerados biosorbentes de bajo costo y una alternativa verde o amigable con el ambiente para la eliminación de diversos contaminantes (Ruiz-Hitzky et al., 2014). Por lo anterior, se propone la aplicación de nanomateriales como adsorbentes de contaminantes inorgánicos y orgánicos en solución acuosa.

En este trabajo se emplearán los nanomateriales hidróxido doble laminar calcinado (HDL550), óxido grafítico (OG) y biocompositos de lignina/sepiolita como materiales adsorbentes en solución acuosa. El HDL550 se aplicará para la adsorción de oxianiones de selenio y diclofenaco, y el OG se utilizará para la adsorción individual y simultánea de los fármacos diclofenaco y sulfametoxazol. Se estudiarán los efectos de las condiciones de operación sobre la capacidad de adsorción y se elucidarán los mecanismos de adsorción. Igualmente, se desarrollarán novedosos bionanocompositos a base de lignina Kraft o lejía negra y la arcilla sepiolita como fase dispersa. Se optimizarán los métodos de síntesis y se evaluarán como adsorbentes de metales, fármacos y colorantes.

REFERENCIAS BIBLIOGRÁFICAS

Ahamad, A., Madhav, S., Singh, A. K., Kumar, A., Singh, P. (2020). Types of water pollutants: Conventional and emerging. In *Sensors in water pollutants monitoring: Role of material* (pp. 21-41). Springer, Singapore.

Akpe, S.G., Ahmed, I., Puthiaraj, P., Yu, K., Ahn, W.S. (2020). Microporous organic polymers for efficient removal of sulfamethoxazole from aqueous solutions. *Micropor. Mesopor. Mat.*, **296**, 109979.

Albadarin, A. B., Ala'a, H., Al-Laqtah, N. A., Walker, G. M., Allen, S. J., Ahmad, M. N. (2011). Biosorption of toxic chromium from aqueous phase by lignin: mechanism, effect of other metal ions and salts. *Chem. Eng. J.*, **169**, 20-30.

Alcântara, A.C., Darder, M., Aranda, P., Ruiz-Hitzky, E. (2014). Polysaccharide–fibrous clay bionanocomposites. *Appl. Clay Sci.*, **96**, 2-8.

Alessandretti, I., Rigueto, C.V.T., Nazari, M.T., Rosseto, M., Dettmer, A. (2021). Removal of diclofenac from wastewater: A comprehensive review of detection, characteristics and tertiary treatment techniques. *J. Environ. Chem. Eng.*, **9**, 106743.

Al-Ghouti, M.A., Da'ana, D.A. (2020). Guidelines for the use and interpretation of adsorption isotherm models: A review. *J. Hazard. Mater.*, **393**, 122383.

Alkhouzaam, A., Qiblawey, H., Khraisheh, M., Atieh, M., Al-Ghouti, M. (2020). Synthesis of graphene oxides particle of high oxidation degree using a modified Hummers method. *Ceram. Int.*, **46**, 23997-24007.

Ayawei, N., Ebelegi, A. N., Wankasi, D. (2017). Modelling and interpretation of adsorption isotherms. *J. Chem.*, 3039817, 1-11.

Banerjee, P., Das, P., Zaman, A., Das, P. (2016). Application of graphene oxide nanoplatelets for adsorption of ibuprofen from aqueous solutions: evaluation of process kinetics and thermodynamics. *Process Saf. Environ. Prot.*, **101**, 45-53.

Benis, K. Z., McPhedran, K. N., Soltan, J. (2022). Selenium removal from water using adsorbents: A critical review. *J. Hazard. Mater.*, **424**, 127603.

Bernard, E., Zucha, W.J., Lothenbach, B., Mäder, U. (2022). Stability of hydrotalcite (Mg-Al layered double hydroxide) in presence of different anions. *Cement and Concrete Research*, **152**, 106674.

Bi, X., Zhang, H., Dou, L. (2014). Layered double hydroxide-based nanocarriers for drug delivery. *Pharmaceutics*, **6**, 298-332.

Bian, H., Gao, Y., Wang, R., Liu, Z., Wu, W., Dai, H. (2018). Contribution of lignin to the surface structure and physical performance of cellulose nanofibrils film. *Cellulose*, **25**, 1309-1318.

Biriukov, D., Fibich, P., Předota, M. (2020). Zeta potential determination from molecular simulations. *J. Phys. Chem. C*, **124**(5), 3159-3170.

Biswas, S., Rashid, T.U., Debnath, T., Haque, P., Rahman, M.M. (2020). Application of chitosan-clay biocomposite beads for removal of heavy metal and dye from industrial effluent. *J. Composites Sci.*, **4**, 16.

Bogunia, M., Makowski, M. (2020). Influence of Ionic Strength on Hydrophobic Interactions in Water: Dependence on Solute Size and Shape. *J. Phys. Chem. B.*, **124**, 10326-10336.

Bonnefille, B., Gomez, E., Courant, F., Escande, A., Fenet, H. (2018). Diclofenac in the marine environment: a review of its occurrence and effects. *Marine pollution bulletin*, **131**, 496-506.

Borah, P., Kumar, M., Devi, P. (2020). Types of inorganic pollutants: metals/metalloids, acids, and organic forms. In *Inorganic Pollutants in Water* (pp. 17-31). Elsevier.

Botas, C., Álvarez, P., Blanco, P., Granda, M., Blanco, C., Santamaría, R., Romasanta, L.J., Verdejo, R., López-Manchado, M.A., Menéndez, R. (2013). Graphene materials with different structures prepared from the same graphite by the Hummers and Brodie methods. *Carbon*, **65**, 156-164.

Bouaziz, Z., Djebbi, M. A., Soussan, L., Janot, J. M., Amara, A. B. H., Balme, S. (2017). Adsorption of nisin into layered double hydroxide nanohybrids and in-vitro controlled release. *Mater. Sci. Eng. C*, **76**, 673-683.

Boukhalfa, N., Boutahala, M., Djebri, N. (2017). Synthesis and characterization of ZnAl-layered double hydroxide and organo-K10 montmorillonite for the removal of diclofenac from aqueous solution. *Adsorpt. Sci. Technol.*, **35**(1-2), 20-36.

Burakov, A.E., Galunin, E.V., Burakova, I.V., Kucherova, A.E., Agarwal, S., Tkachev, A. G., Gupta, V.K. (2018). Adsorption of heavy metals on conventional and nanostructured materials for wastewater treatment purposes: A review. *Ecotox. Environ. Safe.*, **148**, 702-712.

Caicedo, F.M.C., López, E.V., Agarwal, A., Drozd, V., Durygin, A., Hernandez, A.F., Wang, C. (2020). Synthesis of graphene oxide from graphite by ball milling. *Diamond Relat. Mater.*, **109**, 108064.

Campagnolo, L., Morselli, D., Magrì, D., Scarpellini, A., Demirci, C., Colombo, M., Athanassiou, A. Fragouli, D. (2019). Silk fibroin/orange peel foam: an efficient biocomposite for water remediation. *Adv. Sustain. Syst.*, **3**, 1800097.

Carrales-Alvarado, D.H., Rodríguez-Ramos, I., Leyva-Ramos, R., Mendoza-Mendoza, E., Villela-Martínez, D.E. (2020). Effect of surface area and physical–chemical properties of graphite and graphene-based materials on their adsorption capacity towards metronidazole and trimethoprim antibiotics in aqueous solution. *Chem. Eng. J.*, **402**, 126155.

Chaillot, D., Bennici, S., Brendlé, J. (2021). Layered double hydroxides and LDH-derived materials in chosen environmental applications: a review. *Environ. Sci. Pollut. Res.*, **28**, 24375-24405.

Chaudhry, F.N., Malik, M.F. (2017). Factors affecting water pollution: a review. *J. Ecosyst Ecography*, **7**, 1-3.

Cheikh, D., Martín-Sampedro, R., Majdoub, H., Darder, M. (2020). Alginate bionanocomposite films containing sepiolite modified with polyphenols from myrtle berries extract. *Int. J. Biol. Macromol.*, **165**, 2079-2088.

Chen, H., Gao, B., Li, H. (2015). Removal of sulfamethoxazole and ciprofloxacin from aqueous solutions by graphene oxide. *J. Hazard. Mater.*, **282**, 201-207.

Chen, H., Qu, X., Liu, N., Wang, S., Chen, X., Liu, S. (2018). Study of the adsorption process of heavy metals cations on Kraft lignin. *Chem. Eng. Res. Des.*, **139**, 248-258.

Chen, K.L., Liu, L.C., Chen, W.R. (2017). Adsorption of sulfamethoxazole and sulfapyridine antibiotics in high organic content soils. *Environ. Pollut.*, **231**, 1163-1171.

Chetia, M., Goswamee, R.L., Banerjee, S., Chatterjee, S., Singh, L., Srivastava, R.B., Sarma, H.P. (2012). Arsenic removal from water using calcined Mg–Al layered double hydroxide. *Clean Technol. Environ. Policy*, **14**, 21-27.

Chio, C., Sain, M., Qin, W. (2019). Lignin utilization: a review of lignin depolymerization from various aspects. *Renew. Sust. Energ. Rev.*, **107**, 232-249.

Chubar, N., Gerda, V., Megantari, O., Mičušík, M., Omastova, M., Heister, K., Man, P., Fraissard, J. (2013). Applications versus properties of Mg-Al layered double hydroxides provided by their syntheses methods: Alkoxide and alkoxide-free sol-gel syntheses and hydrothermal precipitation. *Chem. Eng. J.*, **234**, 284-299.

Chung, H.K., Kim, W.H., Park, J., Cho, J., Jeong, T.Y., Park, P.K. (2015). Application of Langmuir and Freundlich isotherms to predict adsorbate removal efficiency or required amount of adsorbent. *J. Ind. Eng. Chem.*, **28**, 241-246.

Clogston, J.D., Patri, A.K. (2011). Zeta potential measurement. In: McNeil S. Eds. Characterization of nanoparticles intended for drug delivery. Methods in molecular biology (methods and protocols), vol. 697. pp. 63-70. Humana press.

Constantino, L.V., Quirino, J.N., Monteiro, A.M., Abrão, T., Parreira, P.S., Urbano, A., Santos, M.J. (2017). Sorption-desorption of selenite and selenate on Mg-Al layered double hydroxide in competition with nitrate, sulfate and phosphate. *Chemosphere*, **181**, 627-634.

Crouvisier-Urion, K., da Silva Farias, F.R., Arunatat, S., Griffin, D., Gerometta, M., Rocca-Smith, J.R., Karbowiak, T. (2019). Functionalization of chitosan with lignin to produce active materials by waste valorization. *Green Chemistry*, **21**, 4633-4641.

da Silva, AF., da Silva Duarte, J.L., Meili, L. (2021). Different routes for MgFe/LDH synthesis and application to remove pollutants of emerging concern. *Separat. Purif. Technol.*, **264**, 118353.

Darder, M., Aranda, P., Ruiz-Hitzky, E. (2007). Bionanocomposites: a new concept of ecological, bioinspired, and functional hybrid materials. *Adv. Mater.*, **19**, 1309-1319.

Das, J., Patra, B.S., Baliarsingh, N., Parida, K.M. (2007). Calcined Mg–Fe–CO3 LDH as an adsorbent for the removal of selenite. *J. Colloid Interf. Sci.*, **316**, 216-223.

Das, P., Mandal, B., Gumma, S. (2020). Engineering of structural and surface functional characteristics of graphite oxide nanosheets by controlling oxidation temperature. *Appl. Surf. Sci.*, **504**, 144444.

Das, R. (2018). *Carbon Nanotubes for Clean Water* (pp. 85-106). Switzerland AG: Springer International Publishing.

de Gisi, S., Lofrano, G., Grassi, M., Notarnicola, M. (2016). Characteristics and adsorption capacities of low-cost sorbents for wastewater treatment: a review. *Sustain. Mater. Technol.*, **9**, 10-40.

Dikici, B.A., Claeyssens, F. (2020). Basic principles of emulsion templating and its use as an emerging manufacturing method of tissue engineering scaffolds. *Front. Bioeng. Biotechnol.*, **8**.

Dirany, A., Aaron, S. E., Oturan, N., Sirés, I., Oturan, M. A., Aaron, J. J. (2011). Study of the toxicity of sulfamethoxazole and its degradation products in water by a bioluminescence method during application of the electro-Fenton treatment. *Anal. Bioanal. Chem.*, **400**, 353-360.

Dongil, A.B., Bachiller-Baeza, B., Guerrero-Ruiz, A., Rodríguez-Ramos, I. (2011). Chemoselective hydrogenation of cinnamaldehyde: A comparison of the immobilization of Ru-phosphine complex on graphite oxide and on graphitic surfaces. *J. Catal.*, **282**, 299-309.

dos Santos, G. E. D. S., Ide, A. H., Duarte, J. L. S., McKay, G., Silva, A. O. S., Meili, L. (2020). Adsorption of anti-inflammatory drug diclofenac by MgAl/ layered double hydroxide supported on Syagrus coronata biochar. *Powder Technol.*, **364**, 229-240.

dos Santos, R.M.M., Gonçalves, R.G.L., Constantino, V.R.L., Santilli, C.V., Borges, P.D., Tronto, J., Pinto, F.G. (2017). Adsorption of Acid Yellow 42 dye on calcined layered double hydroxide: Effect of time, concentration, pH and temperature. *Appl. Clay Sci.*, **140**, 132-139.

Dotto, G. L., McKay, G. (2020). Current scenario and challenges in adsorption for water treatment. *J. Environ. Chem. Eng.*, **8**, 103988.

Drzymała, J., Kalka, J. (2020). Ecotoxic interactions between pharmaceuticals in mixtures: diclofenac and sulfamethoxazole. *Chemosphere*, **259**, 127407.

El-Ramady, H. R., Domokos-Szabolcsy, É., Shalaby, T. A., Prokisch, J., Fári, M. (2015). Selenium in agriculture: water, air, soil, plants, food, animals and nanoselenium. *CO2 sequestration, biofuels and depollution*, 153-232.

Epp, J. (2016). X-ray diffraction (XRD) techniques for materials characterization. In *Materials characterization using nondestructive evaluation (NDE) methods*. pp. 81-124. Woodhead Publishing.

Etteieb, S., Magdouli, S., Zolfaghari, M., Brar, S. (2020). Monitoring and analysis of selenium as an emerging contaminant in mining industry: A critical review. *Sci. Total Environ.*, **698**, 134339.

Extremera, R., Pavlovic, I., Pérez, M. R., Barriga, C. (2012). Removal of acid orange 10 by calcined Mg/Al layered double hydroxides from water and recovery of the adsorbed dye. *Chem. Eng. J.*, **213**, 392-400.

Fawell, J., Nieuwenhuijsen, M. J. (2003). Contaminants in drinking water. Environ. Pollut. Health. *British medical bulletin*, **68**, 199-208.

Feldman, D. (2016). Lignin nanocomposites. *J. Macromol. Sci., Part A*, **53**, 382-387.

Feng, Z., Odelius, K., Rajarao, G. K., Hakkarainen, M. (2018). Microwave carbonized cellulose for trace pharmaceutical adsorption. *Chem. Eng. J.*, **346**, 557-566.

Fernández-Costas, C., Gouveia, S., Sanromán, M.A., Moldes, D. (2014). Structural characterization of Kraft lignins from different spent cooking liquors by 1D and 2D Nuclear Magnetic Resonance spectroscopy. *Biomass Bioenergy*, **63**, 156-166.

Fordyce, F. M. (2013). Selenium deficiency and toxicity in the environment. In *Essentials of medical geology* (pp. 375-416). Springer, Dordrecht.

Forgacz, C., Birot, M., Deleuze, H. (2013). Synthesis of porous emulsion-templated monoliths from a pulp mill by-product. *J. Appl. Polym. Sci.*, **129**, 2606-2613.

Forgacz, C., Birot, M., Deleuze, H. (2015). Synthesis of macroporous monolithic materials from a waste renewable source. *J. Appl. Polym. Sci.*, **132**.

Forgacz, C., Caubet, S., Le Guer, Y., Grassl, B., El Omari, K., Birot, M., Deleuze, H. (2013). Synthesis of porous emulsion-templated monoliths using a low-energy emulsification batch mixer. *J. Polym. Environ.*, **21**, 683-691.

Foulet, A., Birot, M., Backov, R., Sonnemann, G., Deleuze, H. (2016). Preparation of hierarchical porous carbonaceous foams from Kraft black liquor. *Mater. Today Commun.*, **7**, 108-116.

Foulet, A., Birot, M., Sonnemann, G., Deleuze, H. (2015). The potential of Kraft black liquor to produce bio-based emulsion-templated porous materials. *React. Funct. Polym.*, **90**, 15-20.

França, D. B., Trigueiro, P., Silva Filho, E. C., Fonseca, M. G., Jaber, M. (2020). Monitoring diclofenac adsorption by organophilic alkylpyridinium bentonites. *Chemosphere*, **242**, 125109.

Frary, B.D. (1986). Manual de operacion del equipo de espectroscopía de absorción atómica. Atomic Absorption at Work. Varian, S.A.

Gao, Z., Sasaki, K., Qiu, X. (2018). Structural memory effect of Mg–Al and Zn–Al layered double hydroxides in the presence of different natural humic acids: process and mechanism. *Langmuir*, **34**, 5386-5395.

Garke, G., Hartmann, R., Papamichael, N., Deckwer, W.D. y Anspach, F.B. (1999). The influence of protein size on adsorption kinetics and equilibria in ion-exchange chromatography. *Sep. Sci. Technol.*, **34**, 2521–2538.

Ge, J., Lian, L., Wang, X., Cao, X., Gao, W., Lou, D. (2022). Coating layered double hydroxides with carbon dots for highly efficient removal of multiple dyes. *J. Hazard. Mater.*, **424**, 127613.

Ge, Y., Li, Z. (2018). Application of lignin and its derivatives in adsorption of heavy metal ions in water: a review. *ACS Sustain. Chem. Eng.*, **6**, 7181-7192.

Ghangrekar, M.M., Chatterjee, P. (2018). Water pollutants classification and its effects on environment. In *Carbon nanotubes for clean water* (pp. 11-26). Springer, Cham.

Gidado, S. M., Akanyeti, İ. (2020). Comparison of Remazol Brilliant Blue Reactive Adsorption on Pristine and Calcined ZnAl, MgAl, ZnMgAl Layered Double Hydroxides. *Water Air Soil Pollut.*,**231**(4), 1-18.

Girish, C. R. (2017). Various isotherm models for multicomponent adsorption: A review. *Inter. J. Civil Eng. Technol.*, **8**, 80-86.

Godlewska, P., Bogusz, A., Dobrzyńska, J., Dobrowolski, R., Oleszczuk, P. (2020). Engineered biochar modified with iron as a new adsorbent for treatment of water contaminated by selenium. *J. Saudi Chem. Soc.*, **24**, 824-834.

Gogoi, A., Mazumder, P., Tyagi, V.K., Chaminda, G.T., An, A.K., Kumar, M. (2018). Occurrence and fate of emerging contaminants in water environment: a review. *Groundw. Sustain. Dev.*, **6**, 169-180.

Gomes, D.S., Gando-Ferreira, L.M., Quinta-Ferreira, R.M., Martins, R.C. (2018) Removal of sulfamethoxazole and diclofenac from water: strategies involving O_3 and H_2O_2, *Environ. Technol.*, **39**, 1658-1669

Gopalakannan, V., Periyasamy, S., Viswanathan, N. (2016). Synthesis of assorted metal ions anchored alginate bentonite biocomposites for Cr (VI) sorption. *Carbohydr. Polym.*, **151**, 1100-1109.

Gu, P., Zhang, S., Li, X., Wang, X., Wen, T., Jehan, R., Alsaedi, A., Hayat, T., Wang, X. (2018). Recent advances in layered double hydroxide-based nanomaterials for the removal of radionuclides from aqueous solution. *Environmental pollution*, **240**, 493-505.

Guerra, A.C.S., de Andrade, M.B., Tonial dos Santos, T.R., Bergamasco, R. (2021). Adsorption of sodium diclofenac in aqueous medium using graphene oxide nanosheets. *Environ. Technol.*, **42**, 2599-2609.

Hadrup, N., Ravn-Haren, G. (2020). Acute human toxicity and mortality after selenium ingestion: A review. *J. Trace Elem. Med. Biol.*, **58**, 126435.

Haseena, M., Malik, M.F., Javed, A., Arshad, S., Asif, N., Zulfiqar, S., Hanif, J. (2017). Water pollution and human health. *Environmental Risk Assessment and Remediation*, **1**.

He, H., Kang, H., Ma, S., Bai, Y., Yang, X. (2010). High adsorption selectivity of ZnAl layered double hydroxides and the calcined materials toward phosphate. *J. Colloid Inter. Sci.*, **343**, 225-231.

He, Y., Xiang, Y., Zhou, Y., Yang, Y., Zhang, J., Huang, H., Shang, C., Luo, L. Gao, J., Tang, L. (2018). Selenium contamination, consequences and remediation techniques in water and soils: a review. *Environ. Res.*, **164**, 288-301.

Hernández, D., Lazo, L., Valdés, L., de Ménorval, L.C., Rozynek, Z., Rivera, A. (2018). Synthetic clay mineral as nanocarrier of sulfamethoxazole and trimethoprim. *Appl. Clay Sci.*, **161**, 395-403.

Hidayah, N.M.S., Liu, W.W., Lai, C.W., Noriman, N.Z., Khe, C.S., Hashim, U., Lee, H.C. (2017). Comparison on graphite, graphene oxide and reduced graphene oxide: Synthesis and characterization. *AIP Conf. Proc.*, **1892**, 150002.

Hiew, B.Y.Z., Lee, L.Y., Lee, X.J., Gan, S., Thangalazhy-Gopakumar, S., Lim, S.S., Pan, G.T., Yang, T.C.K. (2019). Adsorptive removal of diclofenac by graphene oxide: optimization, equilibrium, kinetic and thermodynamic studies. *J. Taiwan Inst. Chem. Eng.*, **98**, 150-162.

Hosni, K., Srasra, E. (2010). Evaluation of phosphate removal from water by calcined-LDH synthesized from the dolomite. *Colloid J.*, **72**, 423-431.

Hu, M., Yan, X., Hu, X., Feng, R., Zhou, M. (2018). High-capacity adsorption of benzotriazole from aqueous solution by calcined Zn-Al layered double hydroxides. *Colloids Surf. A: Physicochem. Eng. Asp.*, **540**, 207-214.

Ibrahim, A.F., Banihashemi, F., Lin, Y.S. (2019). Graphene oxide membranes with narrow inter-sheet galleries for enhanced hydrogen separation. *Chemical Communications*, **55**, 3077-3080.

Ighalo, J.O., Adeniyi, A.G. (2020). Mitigation of Diclofenac pollution in aqueous media by adsorption. *Chem. Bio. Eng. Reviews*, **7**, 50-64.

Iqbal, M.A., Fedel, M. (2019). Ordering and disordering of in situ grown MgAl-layered double hydroxide and its effect on the structural and corrosion resistance properties. *Inter. J. Miner., Metall. Mater.*, **26**, 1570-1577.

Isaacs-Paez, E.D., Leyva-Ramos, R., Jacobo-Azuara, A., Martínez-Rosales, J.M., Flores-Cano, J.V. (2014). Adsorption of boron on calcined AlMg layered double hydroxide from aqueous solutions. Mechanism and effect of operating conditions. *Chem. Eng. J.*, **245**, 248-257.

Jalalian, M., Jiang, Q., Birot, M., Deleuze, H., Woodward, R.T., Bismarck, A. (2018). Frothed black liquor as a renewable cost effective precursor to low-density lignin and carbon foams. *React. Funct. Polym.*, **132**, 145-151.

Jauris, I. M., Matos, C. F., Saucier, C., Lima, E. C., Zarbin, A. J. G., Fagan, S. B., Zanella, I. (2016). Adsorption of sodium diclofenac on graphene: a combined experimental and theoretical study. *Physical Chemistry Chemical Physics*, **18**, 1526-1536.

Ji, H., Wu, W., Li, F., Yu, X., Fu, J., Jia, L. (2017). Enhanced adsorption of bromate from aqueous solutions on ordered mesoporous Mg-Al layered double hydroxides (LDHs). *J. Hazard. Mater.*, **334**, 212-222.

Jianfei, Y., Zixing, F., Liangmeng, N., Qi, G., Zhijia, L. (2020). Combustion characteristics of bamboo lignin from kraft pulping: Influence of washing process. *Renew. Energy*, **162**, 525-534.

Jiang, L., Liu, Y., Liu, S., Hu, X., Zeng, G., Hu, X., Liu, S., Liu, S., Huang, B., Li, M. (2017). Fabrication of β-cyclodextrin/poly (l-glutamic acid) supported magnetic graphene oxide and its adsorption behavior for 17β-estradiol. *Chem. Eng. J.*, **308**, 597-605.

Jiménez-López, B.A., Leyva-Ramos, R., Salazar-Rábago, J.J., Jacobo-Azuara, A., Aragón-Piña, A. (2021). Adsorption of selenium (IV) oxoanions on calcined layered double hydroxides of Mg-Al-CO3 from aqueous solution. Effect of calcination and reconstruction of lamellar structure. *Environ. Nanotechnol., Monit. Manag.*, **16**, 100580.

Karami, Z., Jouyandeh, M., Ali, J. A., Ganjali, M. R., Aghazadeh, M., Maadani, M., Saeb, M. R. (2019). Cure Index for labeling curing potential of epoxy/LDH nanocomposites: A case study on nitrate anion intercalated Ni-Al-LDH. *Prog. Org. Coat.*, **136**, 105228.

Karthik, V., Selvakumar, P., Senthil Kumar, P., Vo, D.V. N., Gokulakrishnan, M., Keerthana, P., Elakkiya, V.T., Rajeswari, R. (2021). Graphene-based materials for environmental applications: a review. *Environ. Chem. Letters*, **19**, 3631-3644.

Kaur, M., Datta, M. (2014). Diclofenac sodium adsorption onto montmorillonite: adsorption equilibrium studies and drug release kinetics. *Adsorption Sci. and Tech.*, **32**(5), 365-387.

Kausar, A. (2018). Polyurethane composite foams in high-performance applications: A review. *Polym. Plast. Technol. Eng.*, **57**, 346-369.

Khadir, A., Mollahosseini, A., Tehrani, R., Negarestani, M. (2020). A review on pharmaceutical removal from aquatic media by adsorption: understanding the influential parameters and novel adsorbents. In *Sustainable Green Chemical Processes and their Allied Applications* (pp. 207-265). Springer, Cham.

Khan, A., Anwer, M. (2020). Advance Techniques for Diclofenac Removal from Pharmaceutical Wastewater: A Review. *Inter. Res. J. Adv. Sci. Hub*, **2**, 26-31.

Khan, A., Wang, J., Li, J., Wang, X., Chen, Z., Alsaedi, A., Hayat, T., Chen, Y., Wang, X. (2017). The role of graphene oxide and graphene oxide-based nanomaterials in the removal of pharmaceuticals from aqueous media: a review. *Environ. Sci. Pollut. Re.*, **24**, 7938-7958.

Khan, M.A., Ghouri, A. M. (2011). Environmental pollution: its effects on life and its remedies. *Res. World: J. Arts, Sci. Commerce*, **2**, 276-285.

Kimmins, S.D., Cameron, N.R. (2011). Functional porous polymers by emulsion templating: recent advances. *Adv. Funct. Mater.*, **21**, 211-225.

Kosmulski, M. (2012). IEP as a parameter characterizing the pH-dependent surface charging of materials other than metal oxides. *Adv. Colloid Interface Sci.*, **171**, 77-86.

Kozlowski, L. P. (2017). Proteome-pI: proteome isoelectric point database. *Nucleic Acids Res.*, **45**(D1), D1112-D1116.

Kukesh, J.S., Pauling, L. (1950). The problem of the graphite structure. The American Mineralogist Crystal Structure Database. American Mineralogist, **35**, 125-125 (_database_code_amcsd 0000049).

Lai, K.C., Lee, L.Y., Hiew, B.Y.Z., Thangalazhy-Gopakumar, S., Gan, S. (2019). Environmental application of three-dimensional graphene materials as adsorbents for dyes and heavy metals: Review on ice-templating method and adsorption mechanisms. *J. Environ. Sci.*, **79**, 174-199.

Lee, S.B., Ko, E.H., Park, J.Y., Oh, J. M. (2021). Mixed metal oxide by calcination of layered double hydroxide: Parameters affecting specific surface area. *Nanomaterials*, **11**, 1153.

Leyva-Ramos, R. (2010). Fundamentos de adsorción en sistemas líquido-sólido. *IBEROARSEN, Tecnologías económicas para el abatimiento de arsénico en aguas, CYTED, Argentina*, **3**, 43-50.

Li, B., Zhang, Y., Zhou, X., Liu, Z., Liu, Q., Li, X. (2016). Different dye removal mechanisms between monodispersed and uniform hexagonal thin plate-like MgAl–CO32--LDH and its calcined product in efficient removal of Congo red from water. *J. Alloys Compd.*, **673**, 265-271.

Li, C., Wei, M., Evans, D.G., Duan, X. (2014). Layered double hydroxide-based nanomaterials as highly efficient catalysts and adsorbents. *Small*, **10**, 4469-4486.

Li, E., Liao, L., Lv, G., Li, Z., Yang, C., Lu, Y. (2018). The interactions between three typical PPCPs and LDH. *Frontiers in chemistry*, **6**, 16.

Li, M., Chowdhury, T., Kraetz, A. N., Jing, H., Dopilka, A., Farmen, L. M., Sinha, S., Chan, C. K. (2019). Layered double hydroxide sorbents for removal of selenium from power plant wastewaters. *Chem. Eng.*, **3**, 20.

Liu, X., Ma, R., Wang, X., Ma, Y., Yang, Y., Zhuang, L., Zhang, S., Jehan, R., Chen, J., Wang, X. (2019). Graphene oxide-based materials for efficient removal of heavy metal ions from aqueous solution: A review. *Environ. Pollut.*, **252**, 62-73.

Liu, Y., Lee, J. Y., Hong, L. (2004). In situ preparation of poly (ethylene oxide)–SiO2 composite polymer electrolytes. *J. Power Sources*, **129**, 303-311.

Lonappan, L., Brar, S. K., Das, R. K., Verma, M., Surampalli, R. Y. (2016). Diclofenac and its transformation products: environmental occurrence and toxicity-a review. *Environ. Int.*, **96**, 127-138.

Lowell, S., Shields, J.E., Thomas, M.A., Thommes, M. (2012). Characterization of porous solids and powders: surface area, pore size and density. Springer Science+Business Media New York.

Lu, L., Li, J., Ng, D.H., Yang, P., Song, P., Zuo, M. (2017). Synthesis of novel hierarchically porous Fe3O4@ MgAl–LDH magnetic microspheres and its superb adsorption properties of dye from water. *J. Ind. Eng. Chem.*, **46**, 315-323.

Lu, Y., Fan, L., Yang, L. Y., Huang, F., Ouyang, X. K. (2020). PEI-modified core-shell/bead-like amino silica enhanced poly (vinyl alcohol)/chitosan for diclofenac sodium efficient adsorption. *Carbohydr. Polym.*, **229**, 115459.

Luengo, C.V., Volpe, M.A., Avena, M.J. (2017). High sorption of phosphate on Mg-Al layered double hydroxides: Kinetics and equilibrium. *J. Environ. Chem. Eng.*, **5**, 4656-4662.

Ma, L., Islam, S.M., Xiao, C., Zhao, J., Liu, H., Yuan, M., Sun, G., Li, H., Ma, S., Kanatzidis, M.G. (2017). Rapid simultaneous removal of toxic anions $[HSeO_3]^-$, $[SeO_3]^{2-}$, and $[SeO_4]^{2-}$, and metals Hg^{2+}, Cu^{2+}, and Cd^{2+} by MoS_4^{2-} intercalated layered double hydroxide. *J. Am. Chem. Soc.,* **139**, 12745-12757.

Malhotra, M., Pal, M., Pal, P. (2020). A response surface optimized nanofiltration-based system for efficient removal of selenium from drinking Water. *J. Water Process Eng.*, **33**, 101007.

Malik, A., Dutta, R., Aggrawal, R., Singh, R., Pal, S.K., Das, C. (2022). Highly efficient hydrotalcite-based adsorbent for aqueous-phase cationic dye removal: structural features, kinetics and isotherm study. *Inter. J. Environ. Sci. Technol.*, 1-14.

Manjunath, S.V., Baghel, R.S., Kumar, M. (2020). Antagonistic and synergistic analysis of antibiotic adsorption on Prosopis juliflora activated carbon in multicomponent systems. *Chem. Engineer. J.*, **381**, 122713.

Mansour, F., Al-Hindi, M., Yahfoufi, R., Ayoub, G. M., Ahmad, M. N. (2018). The use of activated carbon for the removal of pharmaceuticals from aqueous solutions: a review. *Rev. Environ. Sci. Biotechnol.*, **17**, 109-145.

Martínez-Costa, J.I., Leyva-Ramos, R., Padilla-Ortega, E., Aragón-Piña, A., Carrales-Alvarado, D.H. (2018). Antagonistic, synergistic and non-interactive competitive sorption of sulfamethoxazole-trimethoprim and sulfamethoxazole-cadmium (ii) on a hybrid clay nanosorbent. *Sci. Total Environ.*, **640**, 1241-1250.

Mir, Z. M., Bastos, A., Höche, D., Zheludkevich, M. L. (2020). Recent Advances on the Application of Layered Double Hydroxides in Concrete—A Review. *Materials*, **13**, 1426.

Mohammadpour, R., Sadeghi, G. M. M. (2020). Potential use of black liquor as lignin source for synthesis of polyurethane foam. *J. Polym. Res.*, **27**, 1-12.

Molla, A., Li, Y., Mandal, B., Kang, S.G., Hur, S.H., Chung, J.S. (2019). Selective adsorption of organic dyes on graphene oxide: theoretical and experimental analysis. *Appl. Surf. Sci.*, **464**, 170-177.

Moral-Rodríguez, A. I., Leyva-Ramos, R., Ania, C. O., Ocampo-Pérez, R., Isaacs-Páez, E. D., Carrales-Alvarado, D. H., Parra, J. B. (2019). Tailoring the textural properties of an activated carbon for enhancing its adsorption capacity towards diclofenac from aqueous solution. *Environ. Sci. Pollut. R.*, **26**(6), 6141-6152.

Mourid, E. H., Lakraimi, M., Benaziz, L., Elkhattabi, E. H., Legrouri, A. (2019). Wastewater treatment test by removal of the sulfamethoxazole antibiotic by a calcined layered double hydroxide. *Appl. Clay Sci.*, **168**, 87-95.

Nam, S.W., Jung, C., Li, H., Yu, M., Flora, J.R.V., Boateng, L.K., Her, N., Zoh, K.D., Yoon, Y. (2015). Adsorption characteristics of diclofenac and sulfamethoxazole to graphene oxide in aqueous solution. *Chemosphere*, **136**, 20-26.

Omran, A.A.B., Mohammed, A.A., Sapuan, S.M., Ilyas, R.A., Asyraf, M.R.M., Rahimian Koloor, S.S., Petrů, M. (2021). Micro-and nanocellulose in polymer composite materials: a review. *Polymers*, **13**, 231.

Osorio, V., Sanchís, J., Abad, J.L., Ginebreda, A., Farré, M., Pérez, S., Barceló, D. (2016). Investigating the formation and toxicity of nitrogen transformation products of diclofenac and sulfamethoxazole in wastewater treatment plants. *J. Hazard. Mater.*, **309**, 157-164.

Otgonjargal, E., Baek, K., Yang, J.S., Surenjav, E., Khasbaatar, A.D. (2019). Study on removal of Se (IV) using Fe-Mn layered double hydroxides and Fe-Mn Dos (double oxides). *Mongolian J. Chem.*, **20**, 29-37.

Parolini, M. (2020). Toxicity of the Non-Steroidal Anti-Inflammatory Drugs (NSAIDs) acetylsalicylic acid, paracetamol, diclofenac, ibuprofen and naproxen towards freshwater invertebrates: A review. *Sci. Total Environ.*, **740**, 140043.

Pedrosa, M., Da Silva, E.S., Pastrana-Martínez, L.M., Drazic, G., Falaras, P., Faria, J.L., Figueiredo, J.L., Silva, A.M.T. (2020). Hummers' and Brodie's graphene oxides as photocatalysts for phenol degradation. *J. Colloid Interface Sci.*, **567**, 243-255.

Pei, W., Shang, W., Liang, C., Jiang, X., Huang, C., Yong, Q. (2020). Using lignin as the precursor to synthesize Fe3O4@ lignin composite for preparing electromagnetic wave absorbing lignin-phenol-formaldehyde adhesive. *Ind. Crops and Prod.*, **154**, 112638.

Penner, M.H. (2017). Ultraviolet, visible, and fluorescence spectroscopy. In Food analysis (pp.89-106). Springer, Cham.

Peña-Guzmán, C., Ulloa-Sánchez, S., Mora, K., Helena-Bustos, R., López-Barrera, E., Álvarez, J., Rodríguez-Pinzón, M. (2019). Emerging pollutants in the urban water cycle in Latin America: A review of the current literature. *J. Environ. Manage.*, **237**, 408-423.

Plank, J., Sachsenhauser, B. (2009). Experimental determination of the effective anionic charge density of polycarboxylate superplasticizers in cement pore solution. *Cem. Concr. Res.*, **39**, 1-5.

Pourfaraj, R., Fatemi, S.J., Kazemi, S. Y., Biparva, P. (2017). Synthesis of hexagonal mesoporous MgAl LDH nanoplatelets adsorbent for the effective adsorption of Brilliant Yellow. *J. Colloid Interf. Sci.*, **508**, 65-74.

Prasannamedha, G., Kumar, P.S. (2020). A review on contamination and removal of sulfamethoxazole from aqueous solution using cleaner techniques: Present and future perspective. *J. Clean. Prod.*, **250**, 119553.

Qian, Z., Radke, D., Jia, W., Tahtinen, M., Wang, G., Zhao, F. (2018). Bioengineering scaffolds for regenerative engineering. *Encyclopedia Biomed. Eng.*, **1**, 444.

Quiroga, M.M.B., Juncà, M.I., Merino, N.A. (2021). Study of the effect of the LDH cations precursors in the removal of arsenic in aqueous solution. *Water Sci. Technol.*, **83**, 2518-2525.

Rajak, D.K., Pagar, D.D., Kumar, R., Pruncu, C.I. (2019). Recent progress of reinforcement materials: A comprehensive overview of composite materials. *J. Mater. Res. Technol.*, **8**, 6354-6374.

Ramesha, G.K., Kumara, A.V., Muralidhara, H.B., Sampath, S. (2011). Graphene and graphene oxide as effective adsorbents toward anionic and cationic dyes. *J. Colloid Interf. Sci.*, **361**, 270-277.

Rangaraj, V.M., Devaraju, S., Rambabu, K., Banat, F., Mittal, V. (2022). Silver-sepiolite (Ag-Sep) hybrid reinforced active gelatin/date waste extract (DSWE) blend composite films for food packaging application. *Food Chem.*, **369**, 130983.

Rathee, G., Kohli, S., Singh, N., Awasthi, A., Chandra, R. (2020). Calcined Layered Double Hydroxides: Catalysts for Xanthene, 1, 4-Dihydropyridine, and Polyhydroquinoline Derivative Synthesis. *ACS omega*, **5**, 15673-15680.

Rathi, B.S., Kumar, P.S. (2021). Application of adsorption process for effective removal of emerging contaminants from water and wastewater. *Environ. Pollut.*, **280**, 116995.

Rosales de León, A. (1987). Diclofenaco potásico asociado a trimetoprim-sulfametoxazol en el tratamiento de faringoamigdalitis bacterianas agudas. *Invest. med. int*, 168-75.

Rosset, M., Sfreddo, L. W., Hidalgo, G. E. N., Perez-Lopez, O. W., Féris, L. A. (2019). Adsorbents derived from hydrotalcites for the removal of diclofenac in wastewater. *Appl. Clay Sci.*, **175**, 150-158.

Rosset, M., Sfreddo, L. W., Perez-Lopez, O. W., Feris, L. A. (2020). Effect of concentration in the equilibrium and kinetics of adsorption of acetylsalicylic acid on ZnAl layered double hydroxide. *J. Environ. Chem. Eng.*, **8**, 103991.

Rostamian, R., Behnejad, H. (2016). A comparative adsorption study of sulfamethoxazole onto graphene and graphene oxide nanosheets through equilibrium, kinetic and thermodynamic modeling. *Process Saf. Environ. Prot.*, **102**, 20-29.

Rouquerol, J., Rouquerol, F., Llewellyn, P., Maurin, G., Sing, K. S. (2014). *Adsorption by powders and porous solids: principles, methodology and applications*. Academic press.

Ruiz-Hitzky, E. (2001). Molecular access to intracrystalline tunnels of sepiolite. Basis of a presentation given at Materials Discussion No. 3, 24–26 September 2000, University of Cambridge, UK. *J. Mater. Chem.*, **11**, 86-91.

Ruiz-Hitzky, E., Darder, M., Alcântara, A.C., Wicklein, B., Aranda, P. (2014). Recent advances on fibrous clay-based nanocomposites. *Organic-inorganic hybrid nanomaterials*, 39-86.

Ruiz-Hitzky, E., Darder, M., Fernandes, F.M., Wicklein, B., Alcântara, A.C., Aranda, P. (2013). Fibrous clays based bionanocomposites. *Progress Polym. Sci.*, **38**, 1392-1414.

Ruiz-Hitzky, E., Darder, M., Wicklein, B., Fernandes, F.M., Castro-Smirnov, F.A., del Burgo, M.A.M., del Real, G. Aranda, P. (2012). Advanced biohybrid materials based on nanoclays for biomedical applications. In *Nanosystems in engineering and medicine* (Vol. 8548, p. 85480D). International Society for Optics and Photonics.

Sajjadi, M., Ahmadpoor, F., Nasrollahzadeh, M., Ghafuri, H. (2021). Lignin-derived (nano) materials for environmental pollution remediation: Current challenges and future perspectives. *Int. J. Biol. Macromol*.

Salazar-Rábago, J.J., Leyva-Ramos, R., Rivera-Utrilla, J., Ocampo-Pérez, R., Cerino-Córdova, F.J. (2017). Biosorption mechanism of Methylene Blue from aqueous solution onto White Pine (Pinus durangensis) sawdust: Effect of operating conditions. *Sustain. Environ. Res.*, **27**, 32-40.

Santamaría, L., Devred, F., Gaigneaux, E. M., Vicente, M. A., Korili, S. A., Gil, A. (2020). Effect of the surface properties of Me2+/Al layered double hydroxides synthesized from aluminum saline slag wastes on the adsorption removal of drugs. *Microporous Mesoporous Mater.*, **309**, 110560.

Santamaría, L., López-Aizpún, M., García-Padial, M., Vicente, M. A., Korili, S. A., Gil, A. (2020). Zn-Ti-Al layered double hydroxides synthesized from aluminum saline slag wastes as efficient drug adsorbents. *Appl. Clay Sci.*, **187**, 105486.

Santamaría, L., Vicente, M. A., Korili, S. A., Gil, A. (2020). Progress in the removal of pharmaceutical compounds from aqueous solution using layered double hydroxides as adsorbents: A review. *J. Environ. Chem. Eng.*, 104577.

Santhosh, C., Velmurugan, V., Jacob, G., Jeong, S.K., Grace, A.N., Bhatnagar, A. (2016). Role of nanomaterials in water treatment applications: a review. *Chem. Eng. J.*, **306**, 1116-1137.

Santos, R.M.M., Tronto, J., Briois, V., Santilli, C.V. (2017). Thermal decomposition and recovery properties of ZnAl–CO 3 layered double hydroxide for anionic dye adsorption: insight into the aggregative nucleation and growth mechanism of the LDH memory effect. *J. Mater. Chem. A*, **5**, 9998-10009.

Sarıışık, M., Arıcı, M., Topbaş, Ö., Karavana, S. Y., Öztürk, C., Ertan, G. (2013). Design of orthopedic support material containing diclofenac sodium microparticles: preparation and characterization of microparticles and application to orthopedic support material. *Text. Res. J.*, **83**, 1030-1043.

Sathya, A., Ramalingam, S., Nagabalasubramaniyan, P.B., Karpagam, J. (2021). Structure activity investigation, CT complex analysis and spectroscopic investigation on antibiotic drug; Sulfamethoxazole using quantum chemical calculations. *Chem. Phys. Impact*, **3**, 100031.

Sayed, M. R., Abukhadra, M. R., Ahmed, S. A., Shaban, M., Javed, U., Betiha, M. A., Shim, J.J. Rabie, A. M. (2020). Synthesis of advanced MgAl-LDH based geopolymer as a potential catalyst in the conversion of waste sunflower oil into biodiesel: Response surface studies. *Fuel*, *282*, 118865.

Schweitzer, L., Noblet, J. (2018). Water contamination and pollution. In *Green chemistry* (pp. 261-290). Elsevier.

Sharma, P., Das, M.R. (2013). Removal of a cationic dye from aqueous solution using graphene oxide nanosheets: investigation of adsorption parameters. *J. Chem. Engineer. Data*, **58**, 151-158.

Sharma, S., Bhattacharya, A. (2017). Drinking water contamination and treatment techniques. *Appl. Water Sci.*, **7**, 1043-1067.

Shen, Z., Kwon, S., Lee, H.L., Toivakka, M., Oh, K. (2021). Cellulose nanofibril/carbon nanotube composite foam-stabilized paraffin phase change material for thermal energy storage and conversion. *Carbohydr. Polym.*, **273**, 118585.

Sobolev, O. I., Gutyj, B. V., Sobolieva, S. V., Borshch, O. O., Nedashkivsky, V. M., Kachan, L. M., Karkach, P.M., Nedashkivska, N.V., Poroshinska, O.A., Stivbetska, L.S., Emelyanenko, A.A., Shmayun, S.S., Guta, Z. A. (2020). Selenium in natural environment and food chains. A Review. *Ukr. J. Ecol.*, **10**.

Srivastav, A.L., Ranjan, M. (2020). Inorganic water pollutants. In *Inorganic Pollutants in Water* (pp. 1-15). Elsevier.

Stepanova, L. N., Kobzar, E. O., Leont'eva, N. N., Gulyaeva, T. I., Vasilevich, A. V., Babenko, A. V., Serkova, A.N., Salanov, A.N., Belskaya, O. B. (2022). Study of the chemical and phase transformations in the mechanochemical synthesis of the MgAl-layered double hydroxide. *Journal of Alloys and Compounds, 890*, 161902.

Strelko Jr, V., Malik, D.J. (2002). Characterization and metal sorptive properties of oxidized active carbon. *J. Colloid Interf. Sci.*, **250**, 213-220.

Supanchaiyamat, N., Jetsrisuparb, K., Knijnenburg, J.T., Tsang, D.C., Hunt, A.J. (2019). Lignin materials for adsorption: Current trend, perspectives and opportunities. *Bioresour. Technol.*, **272**, 570-581.

Surekha, G., Krishnaiah, K.V., Ravi, N., Suvarna, R.P. (2020). FTIR, Raman and XRD analysis of graphene oxide films prepared by modified Hummers method. *J. Phys. Conf. Ser.*, **1495**, 012012.

Tabelin, C. B., Igarashi, T., Villacorte-Tabelin, M., Park, I., Opiso, E. M., Ito, M., Hiroyoshi, N. (2018). Arsenic, selenium, boron, lead, cadmium, copper, and zinc in naturally contaminated rocks: A review of their sources, modes of enrichment, mechanisms of release, and mitigation strategies. *Sci. Total Environ.*, **645**, 1522-1553.

Taheran, M., Naghdi, M., Brar, S. K., Verma, M., Surampalli, R.Y. (2018). Emerging contaminants: here today, there tomorrow!. *Environ. Nanotech., Monitor. Manag.*, **10**, 122-126.

Takehira, K. (2017). Recent development of layered double hydroxide-derived catalysts−Rehydration, reconstitution, and supporting, aiming at commercial application−. *Appl. Clay Sci.*, **136**, 112-141.

Thommes, M., Kaneko, K., Neimark, A.V., Olivier, J.P., Rodriguez-Reinoso, F., Rouquerol, J., Sing, K.S. (2015). Physisorption of gases, with special reference to the evaluation of surface area and pore size distribution (IUPAC Technical Report). *Pure Appl. Chem.*, **87**, 1051-1069.

Tian, N., Zhou, Z., Tian, X., Yang, C., Li, Y. (2017). Superior capability of MgAl2O4 for selenite removal from contaminated groundwater during its reconstruction of layered double hydroxides. *Sep. Purif. Technol.*, **176**, 66-72.

Ulubay, M., Yurt, K.K., Kaplan, A.A., Atilla, M.K. (2018). The use of diclofenac sodium in urological practice: a structural and neurochemical based review. *J. Chem. Neuroanatomy*, **87**, 32-36.

Van Tran, T., Nguyen, D. T. C., Le, H. T., Vo, D. V. N., Nanda, S., Nguyen, T. D. (2020). Optimization, equilibrium, adsorption behavior and role of surface functional groups on graphene oxide-based nanocomposite towards diclofenac drug. *J. Environ. Sci*.

Velazquez-Herrera, F.D., Fetter, G., Rosato, V., Pereyra, A.M., Basaldella, E.I. (2018). Effect of structure, morphology and chemical composition of Zn-Al, Mg/Zn-Al and Cu/Zn-Al hydrotalcites on their antifungal activity against A. niger. *J. Environ. Chem. Eng.*, **6**, 3376-3383.

Voigt, C., Hubálková, J., Giesche, H., Aneziris, C.G. (2020). Intrusion and extrusion mercury porosimetry measurements at Al2O3–C-Influence of measuring parameter. *Microporous Mesoporous Mater.*, **299**, 110125.

Wang, J., Chen, B. (2015). Adsorption and coadsorption of organic pollutants and a heavy metal by graphene oxide and reduced graphene materials. *Chem. Engineer. J.*, **281**, 379-388.

Wang, J., Guo, X. (2020). Adsorption isotherm models: Classification, physical meaning, application and solving method. *Chemosphere*, **258**, 127279.

Wang, J., Wang, S. (2018). Microbial degradation of sulfamethoxazole in the environment. *Appl. Biotechnol.*, **102**, 3573-3582.

Wang, L., Shi, C., Pan, L., Zhang, X., Zou, J. J. (2020). Rational design, synthesis, adsorption principles and applications of metal oxide adsorbents: A review. *Nanoscale*, **12**, 4790-4815.

Wang, T., Cheng, Z., Wang, B., Ma, W. (2012). The influence of vanadate in calcined Mg/Al hydrotalcite synthesis on adsorption of vanadium (V) from aqueous solution. *Chem. Eng. J.*, **181**, 182-188.

Wang, X., Cai, Y., Han, T., Fang, M., Chen, K., Tan, X. (2020). Phosphate functionalized layered double hydroxides (phos-LDH) for ultrafast and efficient U (VI) uptake from polluted solutions. *J. Hazard. Mater.*, **399**, 123081.

Wang, Y., Pan, C., Chu, W., Vipin, A.K., Sun, L. (2019). Environmental remediation applications of carbon nanotubes and graphene oxide: Adsorption and catalysis. *Nanomaterials*, **9**, 439.

Wang, Z., Song, Y., Zou, J., Li, L., Yu, Y., Wu, L. (2018). The cooperation effect in the Au–Pd/LDH for promoting photocatalytic selective oxidation of benzyl alcohol. *Catal. Sci. Technol.*, **8**, 268-275.

Wu, L., Du, C., He, J., Yang, Z., Li, H. (2020). Effective adsorption of diclofenac sodium from neutral aqueous solution by low-cost lignite activated cokes. *J. Hazard. Mater.*, **384**, 121284.

Xu, H., Zhu, S., Xia, M., Wang, F. (2021). Rapid and efficient removal of diclofenac sodium from aqueous solution via ternary core-shell CS@ PANI@ LDH composite: Experimental and adsorption mechanism study. *J. Hazard. Mater.*, **402**, 123815.

Xu, Z., Fan, J., Zheng, S., Ma, F., Yin, D. (2009). On the adsorption of tetracycline by calcined magnesium-aluminum hydrotalcites. *J. Environ. Quality*, **38**, 1302-1310.

Yan, Q., Arango, R., Li, J., Cai, Z. (2021). Fabrication and characterization of carbon foams using 100% Kraft lignin. *Mater. Des.*, **201**, 109460.

Yan, Z., Zhu, B., Yu, J., Xu, Z. (2016). Effect of calcination on adsorption performance of Mg–Al layered double hydroxide prepared by a water-in-oil microemulsion method. *RSC Adv.*, **6**(55), 50128-50137.

Yang, K., Yan, L.G., Yang, Y.M., Yu, S.J., Shan, R.R., Yu, H.Q., Zhu,B.C., Du, B. (2014). Adsorptive removal of phosphate by Mg–Al and Zn–Al layered double hydroxides: kinetics, isotherms and mechanisms. *Separat. Purif. Technol.*, **124**, 36-42.

Yang, L., Shahrivari, Z., Liu, P. K., Sahimi, M., Tsotsis, T. T. (2005). Removal of trace levels of arsenic and selenium from aqueous solutions by calcined and uncalcined layered double hydroxides (LDH). *Ind. Eng. Chem. Res.*, **44**, 6804-6815.

Ye, H., Liu, S., Yu, D., Zhou, X., Qin, L., Lai, C., Qin, F., Zhang, M., Chen, W., Chen, W., Xiang, L. (2022). Regeneration mechanism, modification strategy, and environment application of layered double hydroxides: Insights based on memory effect. *Coord. Chem. Rev.*, **450**, 214253.

Younes, H.A., Khaled, R., Mahmoud, H.M., Nassar, H.F., Abdelrahman, M.M., El-Ela, F.I.A., Taha, M. (2019). Computational and experimental studies on the efficient removal of diclofenac from water using ZnFe-layered double hydroxide as an environmentally benign absorbent. *J. Taiwan Chem. Eng.*, **102**, 297-311.

Yu, O., Kim, K.H. (2020). Lignin to materials: A focused review on recent novel lignin applications. *Appl. Sci.*, **10**, 4626.

Yu, W., Sisi, L., Haiyan, Y., Jie, L. (2020). Progress in the functional modification of graphene/graphene oxide: A review. *RSC Advances*, **10**, 15328-15345.

Zhang, M., Wang, F., Long, Y., Yu, L., Yang, C., Wen, M., Yu, X., Tian, Y., Zhao, M. (2022). Improving the carbonation resistance of alkali-activated slag mortars by calcined Mg/Al layered double hydroxides. *Appl. Clay Sci.*, **216**, 106379.

Zhang, S., Wang, Z., Zhang, Y., Pan, H., Tao, L. (2016). Adsorption of methylene blue on organosolv lignin from rice straw. *Procedia Environ. Sci.*, **31**, 3-11.

Zhang, T., Sanguramath, R.A., Israel, S., Silverstein, M.S. (2019). Emulsion templating: porous polymers and beyond. *Macromolecules*, **52**, 5445-5479.

Zhao, Y., Liu, F., Qin, X. (2017). Adsorption of diclofenac onto goethite: adsorption kinetics and effects of pH. *Chemosphere*, **180**, 373-378.

Zheng, Y., Wang, Y., Zheng, M., Wang, G., Zhao, H. (2022). Exposed to Sulfamethoxazole induced hepatic lipid metabolism disorder and intestinal microbiota changes on zebrafish (Danio rerio). *Comp. Biochem. Physiol. Part C: Toxicol. Pharmacol.*, **253**, 109245.

Zhou, J., Su, Y., Zhang, J., Xu, X., Zhao, J., Qian, G., Xu, Y. (2015). Distribution of OH bond to metal-oxide in Mg3− xCaxFe-layered double hydroxide (x= 0–1.5): Its role in adsorption of selenate and chromate. *Chemical Engineering Journal*, *262*, 383-389.

Zhou, W., Apkarian, R., Wang, Z.L., Joy, D. (2006). Fundamentals of scanning electron microscopy (SEM). In: Scanning microscopy for nanotechnology. Springer, New York, pp. 1-40.

Zhu, J., Qian, Z., Eid, M., Zhan, F., Ismail, M.A., Li, J., Li, B. (2021). Foaming and rheological properties of hydroxypropyl methylcellulose and welan gum composite system: The stabilizing mechanism. *Food Hydrocoll.*, **112**, 106275.

Zhuang, S., Chen, R., Liu, Y., Wang, J. (2020). Magnetic COFs for the adsorptive removal of diclofenac and sulfamethazine from aqueous solution: Adsorption kinetics, isotherms study and DFT calculation. *J. Hazard. Mater.*, **385**, 121596.

Zuo, J.M., Spence, J.C. (2017). Advanced transmission electron microscopy. Advanced Transmission Electron Microscopy, ISBN 978-1-4939-6605-9. *Springer Science+ Business Media New York*.