UNIVERSITI PUTRA MALAYSIA

SYNTHESIS OF HYPERCROSSLINKED POLY(ACRYLONITRILE-*CO*-ETHYLENE GLYCOL DIMETHACRYLATE-*CO*-VINYLBENZYL CHLORIDE) AS ADSORBENT FOR PHARMACEUTICALS

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By

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

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Chairman : Siti Nurul Ain Md. Jamil, PhD
Faculty : Science

Pharmaceuticals are frequently present in water at concentrations in the $\mu g.L^{-1}$ to $ng.L^{-1}$ range and this range is considered to be a possible threat to the environment. The presence of pharmaceuticals caused sexual disruption in wild fish and harmful to the aquatics. The present work describes the preparation of porous polymeric adsorbent to adsorb pharmaceuticals from water. Ethylene glycol dimethacrylate (EGDMA) was used as a crosslinker in poly(acrylonitrile (AN)-*co*-vinylbenzyl chloride (VBC)) to investigate the effect of long-chain crosslinker to the porosity of the terpolymer system. Poly(acrylonitrile-*co*-ethylene glycol dimethacrylate-*co*-vinylbenzyl chloride) (poly(AN-*co*-EGDMA-*co*-VBC)) with different feed mole ratios of AN and EGDMA were synthesized via suspension polymerization method and further hypercrosslinked by Friedel-Crafts reaction. The performance of the terpolymeric adsorbent to adsorb polar analyte is evaluated by adsorbing each of the pharmaceuticals, metformin (MET) and diclofenac (DCF) from aqueous solution at different conditions in a batch system. The isotherm and kinetic studies were carried out by using batch adsorption data.

The ratio of AN/EGDMA/VBC were varied to 20/70/10, 25/65/10 and 30/60/10 (mol%). Poly(AN-*co*-EGDMA-*co*-VBC) 20/70/10 obtained the highest percentage yield (86%) compared to the other terpolymers. The FT-IR spectra confirmed the successful of polymerization due to the appearance of absorption bands of C≡N, C=O, C-O-C and C-Cl groups in the spectra of all ratios of terpolymers. The absorption band at 1251 cm^{-1} that was assigned to the C-Cl vibrations was less intense in all hypercrosslinked (HXL) poly(AN-*co*-EGDMA-*co*-VBC) polymers, confirming that the hypercrosslinking reaction was successful. The microanalysis showed the increasing of carbon, hydrogen and oxygen contents with the decreasing of nitrogen content of the terpolymers as the mole ratios of EGDMA increased. The Field Emission Scanning Electron Microscopy (FESEM) micrographs showed that poly(AN-*co*-EGDMA-*co*-VBC) and HXL poly(AN-*co*-EGDMA-*co*-VBC) have spherical particle structures. Based on the EDX analysis, the chlorine content of polymers decreased after the hypercrosslinking reaction indicating that the chloromethyl groups were being consumed during hypercrosslinking reaction. Poly(AN-*co*-EGDMA-*co*-VBC) 20/70/10 showed the highest specific surface area (363 $m^2.g^{-1}$), micropore area (33 $m^2.g^{-1}$), total pore volume (0.482 $cm^3.g^{-1}$) and micropore

volume (0.025 $cm^3.g^{-1}$). Broad mesopores range from 2–10 nm are the main pores for all terpolymers to indicate that mesopores are dominant for the polymers. Pore size distribution (PSD) estimated by Barrett-Joyner-Halenda (BJH) method revealed that all terpolymers are centred at around 5–8 nm, which confirmed that terpolymers prepared in this study are mesoporous materials.

The Langmuir isotherm showed good agreement for the adsorption of MET (R^2 of 0.9637) and DCF (R^2 of 0.9689) with maximum adsorption capacities of 5.1 $mg.g^{-1}$ and 61.0 $mg.g^{-1}$, respectively. The pseudo-second-order was observed to have better R^2 compared to the other models for both MET and DCF. After four cycles of adsorption-desorption process, DCF and MET removal decreased from 99% to 78% and 76% to 72%, respectively. Based on experimental findings, HXL poly(AN-*co*-EGDMA-*co*-VBC) polymer is a potential functional regenerable adsorbent to remove pharmaceuticals from liquid environment.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Sarjana Sains

SINTESIS HIPERTAUT SILANG POLI(AKRILONITRIL-*KO*-ETILENA GLIKOL DIMETAKRILAT-*KO*-VINILBENZIL KLORIDA) SEBAGAI PENJERAP UNTUK FARMASEUTIKAL

Oleh

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Farmaseutikal biasanya terdapat di dalam air pada kepekatan μg.L^{-1} hingga ng.L^{-1} dan julat ini dianggap sebagai potensi ancaman terhadap alam sekitar. Kehadiran farmaseutikal menyebabkan gangguan seksual terhadap ikan liar dan berbahaya bagi kehidupan akuatik. Kajian ini menerangkan penyediaan penjerap polimer berliang untuk menjerap farmaseutikal dari air. Etilena glikol dimetakrilat (EGDMA) digunakan sebagai pentaut silang dalam poli(akrilonitril (AN)-*ko*-vinilbenzil klorida (VBC)) untuk menyiasat kesan rantaian taut silang yang panjang terhadap keliangan sistem terpolimer. Poli(akrilonitril-*ko*-etilina glikol dimetakrilat-*ko*-vinilbenzil klorida) (poli(AN-*ko*-EGDMA-*ko*-VBC)) dengan berbeza mol AN dan EGDMA disintesis melalui kaedah pempolimeran suspensi dan hipertaut silang oleh reaksi Friedel-Kraf. Prestasi penjerap terpolimer untuk menjerap analit polar dinilai dengan menjerap setiap farmaseutikal, metformin (MET) dan diklofenak (DCF) dari larutan berair pada keadaan operasi yang pelbagai dalam sistem kumpulan. Kajian isoterma dan kinetik dilakukan dengan menggunakan maklumat penjerapan kumpulan.

Nisbah AN/EGDMA/VBC divariasikan kepada 20/70/10, 25/65/10 dan 30/60/10 (mol%). Poli(AN-*ko*-EGDMA-*ko*-VBC) 20/70/10 memperoleh hasil tertinggi (86%) berbanding terpolimer lain. Spektrum FT-IR mengesahkan kejayaan pempolimeran kerana kemunculan jalur penyerapan kumpulan C≡N, C=O, C-O-C dan C-Cl dalam spektrum semua nisbah terpolimer. Jalur penyerapan pada 1251 cm^{-1} yang diberikan pada getaran C-Cl kurang kuat pada semua polimer hipertaut silang (HXL) poli(AN-*ko*-EGDMA-*ko*-VBC), yang mengesahkan bahawa tindak balas hipertaut silang telah berjaya. Analisis mikro menunjukkan peningkatan kandungan karbon, hidrogen dan oksigen dengan penurunan kandungan nitrogen untuk terpolimer ketika nisbah mol EGDMA meningkat. Mikrograf Elektron Pengimbasan Pelepasan Medan (FESEM) menunjukkan bahawa poli(AN-*ko*-EGDMA-*ko*-VBC) dan HXL poli(AN-*ko*-EGDMA-*ko*-VBC) mempunyai struktur zarah sfera. Berdasarkan analisis EDX, kandungan klorin polimer menurun setelah tindak balas hipertaut silang menunjukkan bahawa kumpulan klorometil digunakan semasa reaksi hipertaut silang. Poli(AN-*ko*-EGDMA*ko*-VBC) 20/70/10 menunjukkan luas permukaan spesifik tertinggi (363 m^2.g^{-1}), luas mikroliang (33 m^2.g^{-1}), jumlah isipadu liang (0.482 cm^3.g^{-1}) dan isipadu mikroliang (0.025 cm^3.g$^-$

^{1}). Julat antara 2-10 nm adalah liang utama bagi semua terpolimer untuk menunjukkan bahawa mesoliang adalah dominan bagi polimer. Taburan saiz liang (PSD) yang dianggarkan oleh kaedah Barrett-Joyner-Halenda (BJH) menunjukkan bahawa semua terpolimer berpusat pada sekitar 5-8 nm, yang mengesahkan bahawa terpolimer yang disediakan dalam kajian ini adalah bahan mesoliang.

Isoterma Langmuir menunjukkan persetujuan yang baik untuk penjerapan MET (R^2 = 0.9637) dan DCF (R^2 = 0.9689) dengan kapasiti penjerapan maksimum masing-masing 5.1 $mg.g^{-1}$ dan 61.0 $mg.g^{-1}$. Urutan pseudo-kedua mempunyai R^2 yang lebih baik berbanding dengan model lain untuk MET dan DCF. Selepas empat kitaran proses penjerapan-penyahpisiran, penyingkiran DCF dan MET masing-masing menurun dari 99% menjadi 78% dan 76% menjadi 72%. Berdasarkan dapatan eksperimen, polimer HXL poli(AN-*ko*-EGDMA-*ko*-VBC) merupakan penjerap terfungsi yang berpotensi untuk dijana semula untuk menyingkirkan farmaseutikal daripada persekitaran cecair.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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This is to confirm that:

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C_0	Initial pharmaceutical concentrations	$mg.L^{-1}$
C_e	Equilibrium pharmaceutical concentrations	$mg.L^{-1}$
C_t	Equilibrium pharmaceutical concentrations at any time t	$mg.L^{-1}$
m	Mass of adsorbent	g
V	Volume of pharmaceutical solution	L
q_e	Adsorption capacity at equilibrium	$mg.g^{-1}$
q_t	Adsorption capacity at any time t	$mg.g^{-1}$
q_{max}	Maximum adsorption capacity	$mg.g^{-1}$
$q_{e(cal)}$	Calculated adsorption capacity	$mg.g^{-1}$
$q_{e(exp)}$	Experimental adsorption capacity	$mg.g^{-1}$
K_L	Langmuir constant	$L.mg^{-1}$
K_{IPD}	Intraparticle diffusion rate constant	$mg.g^{-1}.min^{-1/2}$
K_F	Freundlich constant	$L.mg^{-1}$
R_L	Separation factor	Dimensionless
n	Surface heterogeneity	Dimensionless
C_{IPD}	Boundary layer thickness effect	-

LIST OF ABBREVIATIONS

AN	Acrylonitrile
EGDMA	Ethylene glycol dimethacrylate
VBC	Vinylbenzyl chloride
HXL	Hypercrosslinked
PAN	Poly(acrylonitrile)
Poly(AN-*co*-EGDMA-*co*-VBC)	Poly(acrylonitrile-*co*-ethylene glycol dimethacrylate-*co*-vinylbenzyl chloride)
DCF	Diclofenac
MET	Metformin
FT-IR	Fourier Transform Infrared
FESEM	Field Emission Scanning Electron Microscopy
CHNS	Carbon, hydrogen, nitrogen and sulphur
EDX	Energy Dispersive X-Ray
BET	Brunauer-Emmett-Teller
PFO	Pseudo-first-order
PSO	Pseudo-second-order

CHAPTER 1

INTRODUCTION

1.1 Background of the study

Water is vital for both food production and population growth. The existence of water contamination threatens aquatic biodiversity and causes human and animal diseases. Water pollution usually caused by the irresponsibility authorities who have refused to handle waste in accordance with the requirements of the health organisation. Untreated industrial effluents will, in the long run, lead to major disasters in ecosystem life and will have the worst impact on future generations. Untreated effluents settled into water had led to polluted and toxic waste being transported to water sources. Contaminated water remains in water supply and causes environmental problems for several years as long as no meaningful action is taken to address this global crisis.

Many pathways, such as metabolic excretion by the body, inadequate disposal, and continuous release from sources, comprising public, hospital, agricultural and industrial effluents, have contributed to the continuous release of pharmaceutical contaminants into the environment. As a result of their toxicity, which affects global health, pharmaceuticals that have eventually been found in discharged effluents are currently a major concern. Most pharmaceutical compounds may have toxic effects if they are exposed to human and aquatic life in the long term, even at low concentrations (Wilkinson et al., 2019).

Removal of pharmaceuticals has become of great interest to researchers due to their low biodegradability, inadequate water removal and pharmaceutical activity, even at low concentrations. Various methods have been reported for pharmaceutical uptake, such as ion exchange, membrane separation, biodegradation, and adsorption (Zhou et al., 2018; Moreira et al., 2018; Behboudi et al., 2017; Zheng et al., 2017). Ion exchange at high concentrations of pollutants is cost-effective but requires high maintenance costs. Membrane separation is too expensive due to its high energy consumption and the cost of membrane restoration is needed. Biodegradation is cost-effective but has poor removal capacity. In this study, adsorption, which is the most commonly used technology, was used to remove aqueous pharmaceuticals. This is due to its simplicity, design flexibility, low cost, sorbent regeneration, varied adsorption mechanisms and adaptability to a wide range of pharmaceuticals that benefit from wastewater treatment. In this study, the adsorbent was produced by synthesizing polymers containing specific functional groups that were manipulated to make adsorbents active in the direction of polar pharmaceutical molecules.

1.2 Polymerization

Polymerization is a process of linking monomer molecules together by chemical reaction to the production of polymers. Various polymerization methods, such as suspension, emulsion, precipitation, dispersion, and seed, are used for the synthesis of polymer particles (Chaudhary and Sharma, 2019). In the present work, suspension polymerization was applied to the preparation of the polymer adsorbent. Suspension polymerization was chosen as a water-based synthesis that is performed under mild reaction conditions in a shorter time but still produces high yields.

Numerous studies have reported the preparation of polymers by introducing monomers and comonomers into reactive polymer chains to form crosslinked polymers (El-Newehy et al., 2014). Polymers may be copolymerized or terpolymerized to increase the polarity, selectivity and surface area of the polymer. As a result, acrylonitrile was used as a monomer for the preparation of terpolymer in this study due to its polar nitrile functional group, which helps to increase the hydrophilicity and polarity of the terpolymer. Ethylene glycol dimethacrylate (EGDMA) was selected as a crosslinker for the introduction of a functional carbonyl group into the polymeric system. Apart from increasing polarity, the long and flexible EGDMA chain may favour the accessibility of the analyte molecules to the EGDMA functional groups (Jose et al., 2003). In the meantime, vinylbenzyl chloride (VBC) was used to exploit the methyl chloride groups in the VBC unit during hypercrosslinking via Friedel-Crafts reaction. Hypercrosslinking reactions were then performed for the formation of 3D network and to increase the surface area of the terpolymer. The polymer-based adsorbent was used to adsorb diclofenac and metformin from the aqueous solution.

1.3 Problem statement

This study focused on the removal of diclofenac and metformin from aqueous solution using adsorbent based on polymers; hypercrosslinked (HXL) poly(acrylonitrile-*co*-ethylene glycol dimethacrylate-*co*-vinylbenzyl chloride) (poly(AN-*co*-EGDMA-*co*-VBC)).

Adsorbent, such as activated carbon, needs high energy in production, high cost of production, difficult to regenerate for industrial applications (Tomul et al., 2019). Biosorbent derived from the agricultural and industrial waste also has been explored in removing pharmaceuticals. Based on Li et al. (2019), the biosorbents (biochar, macro-algae, and word chippings) were proved as effective as activated carbon. However, high energy production, plenty of time needed for the cultivation process prior to its use and high doses of biosorbent required; associated with disposal problem.

The polymer-based adsorbent is an alternative adsorption material due to the ease and variety of modifications that can be made on the polymer surface. Generally, the characteristics of pharmaceutical molecules include different surface charge, polar, non-polar, hydrophobic, and hydrophilic. Polymer-based adsorbents have been shown to be useful in the removal of polar pharmaceuticals in solution. This was demonstrated by diverse pharmaceutical removal studies such as salicylic acid using adsorbent based on polymers (Zhou et al., 2018).

Poly(acrylonitrile) (PAN) is an excellent material for the production of ultrafiltration membranes, hollow fibers for reverse osmosis and fibers for special textiles. Oxidized PAN fibers has good resistance to organic solvents, excellent in mechanical strength, has high thermal stability and good compatibility with certain polar substances (Liu et al., 2011). Nevertheless, PAN has high nitrile-nitrile dipolar interactions along its repeating units that lead to low moisture absorption, hydrophobicity, and lack of active functionality (Mishra et al., 2011). In addition, PAN has low specific surface areas that resulted to low adsorption capacity. For this reason, PAN was usually polymerized with vinyl and acrylic monomers to weaken the dipole-dipole interactions as well as to increase PAN hydrophilicity, and polarity resulting from the incorporation of polar functional groups introduced by polar monomers. These improved PAN polarity and hydrophilicity resulted in a high percentage of polar analyte/pharmaceutical removal in aqueous solution.

In order to manipulate the characteristics of the PAN, in this study, acrylonitrile (AN) was copolymerized with EGDMA and VBC to enhance the properties of PAN as an adsorbent. The EGDMA was chosen as a crosslinking monomer due to its potential to overcome the shortcoming of PAN by interrupting the high nitrile-nitrile dipolar interactions along the PAN chains. The carbonyl (-C=O) functional groups in EGDMA was reported to improve the hydrophilicity and polarity which then allow a high affinity to the aqueous phase and does not exhibit steric constraints when it is used as an adsorbent (Galicia-Aguilar et al., 2017). Polarity improvement by the inclusion of EGDMA in the terpolymer system will then facilitate the adsorption of polymer towards polar analyte. Furthermore, incorporation of VBC in the polymeric system helps in the hypercrosslinking of poly(AN-*co*-EGDMA-*co*-VBC) via Friedel-Crafts reaction. The reaction involved the conversion of chloromethyl group into methylene bridges that are formed between adjacent phenyl rings and therefore, lead to the development of abundant pores inside the polymer.

Most of the polymerization methods, such as suspension, emulsion, precipitation, dispersion and seeds used to synthesize polymer particles, consume a lot of energy, time and chemical solvents that tend to produce more chemical waste (Patiño-Herrera et al., 2019). Apart from that, several studies in producing hypercrosslinked polymer involved toxic solvent such as nitrobenzene as solvent. The current study in producing HXL poly(AN-*co*-EGDMA-*co*-VBC) however, makes several noteworthy contributions to the high recovery poly(AN-*co*-EGDMA-*co*-VBC) with more feasible condition; synthesis at mild temperature with the consumption of economical and non-hazardous deionized water as reaction medium, low chemical consumption and 1,2-dichloroethane (DCE) as less toxic solvent in hypercrosslinking reaction. Besides, the polymerization was shorter with less energy usage by using mild temperature but yet obtained high polymerization yield.

The presence of pharmaceuticals in the environment particularly in water has attracted the attention of the researchers due to its potential as an endocrine disruptor, carcinogenicity, poor biodegradability, low removal percentage and potential toxic effects in human and aquatic life. Pharmaceuticals are usually present in water at concentrations in the $\mu g.L^{-1}$ to $ng.L^{-1}$ range, which is considered to be a potential threat to the environment (Wilkinson et al., 2019; Phonsiri et al., 2019). Poor biodegradability of pharmaceuticals can lead to human consumption of contaminated drinking water. In addition, exposure of pharmaceuticals to aquatic life can affect their growth, trigger antioxidant defence reactions and inhibit detoxification mechanisms (Duarte et al., 2020).

Diclofenac and metformin are pharmaceuticals that are classified as the most commonly used drugs by human and widely produced as effluent waste in many industrial sectors. Diclofenac influenced fish metabolism by increasing energy intake within the muscle and thereby reducing fish net energy (Duarte et al., 2020). Meanwhile, the exposure of fish to metformin in wastewater effluent can caused intersex gonads and size reduction of the male fish and also fecundity reduction (Crago et al., 2016; Niemuth and Klaper, 2015).

Therefore, the ability of HXL poly(AN-*co*-EGDMA-*co*-VBC) to remove pharmaceuticals (diclofenac and metformin) with different effect of parameters were carried out. The adsorption study was extended by predicting the equilibriums and kinetics of the adsorption of pharmaceuticals towards the HXL poly(AN-*co*-EGDMA-*co*-VBC) polymer.

1.4 Research goal and objectives

The main goal of this project is to investigate the efficacy of newly developing polymeric adsorbent, HXL poly(AN-*co*-EGDMA-*co*-VBC) terpolymer, for adsorptive removal of pharmaceuticals from aqueous solution. These goals would be achieved via the following objectives:

1. To synthesize poly(AN-*co*-EGDMA-*co*-VBC) via suspension polymerization and hypercrosslink the terpolymer by Friedel-Crafts reaction.
2. To investigate the uptake of diclofenac (DCF) and metformin (MET) onto HXL terpolymer from aqueous solution in batch adsorption system.
3. To study the equilibrium and the kinetics of batch adsorption process of DCF and MET onto HXL terpolymer in aqueous solution.

1.5 Scope of the study

This research focused on the preparation and application of HXL poly(AN-*co*-EGDMA-*co*-VBC) as a potential large-scale polymer-based adsorbent to capture pharmaceuticals in aqueous solution. The optimized poly(AN-*co*-EGDMA-*co*-VBC) was hypercrosslinked to produce HXL poly(AN-*co*-EGDMA-*co*-VBC). The HXL poly(AN-*co*-EGDMA-*co*-VBC) with the highest surface area was selected as adsorbents for the removal of MET and DCF from aqueous solution. Influence of several operating parameters such as pharmaceutical concentration, pH, contact time and adsorbent dose on the adsorptive pharmaceutical removal efficiency of the polymeric adsorbents was investigated. Further adsorption study was implemented through equilibrium and kinetic studies.

1.6 Research novelty

The hypercrosslinked polymeric adsorbent has a broad range of physicochemical properties that make them particularly attractive as separation and reactive media for wastewater treatment and water purification. Pharmaceutical compounds eventually were found in the wastewater's effluent. However, to date, the application of HXL poly(AN-*co*-EGDMA-*co*-VBC) polymer in batch adsorption studies to adsorb pharmaceuticals has not been reported elsewhere. Thus, in the present work, evaluation of batch adsorption system was carried out using HXL terpolymer adsorbent. The mechanism of pharmaceuticals adsorption onto HXL poly(AN-*co*-EGDMA-*co*-VBC) polymer and adsorbent regeneration were investigated, in assessing the industrial viability of the prepared functional adsorbent.

1.7 Thesis layout

This thesis consists of five chapters, organized as:

- Chapter one: Introduction, provides a general introduction on pharmaceutical bearing wastewater and brief review about the treatment methods, related problems, objectives, novelty and research scope.
- Chapter two: Presents detail literature review related to polymer and its application in pharmaceutical uptake from the aquatic environment.
- Chapter three: The procedure for polymer synthesis, hypercrosslinking reaction, as well as adsorption experimentation are highlighted.
- Chapter four: Results and discussion regarding polymer yields, characterization, and its application in pharmaceutical adsorption studies.
- Chapter five: Conclusion and recommendations, this chapter reviews the obtained research findings and suggestions for feasible future

REFERENCES

Abdullah, N., & Cormack, P.A.G. (2015). Non-Aqueous Dispersion (NAD) Polymerisation-Based Synthetic Route to Hypercrosslinked Polymer: Effect of Reaction Temperature and Solvent System on Specific Surface Area. *Advanced Materials Research*, *1134*, 198–202.

Adewuyi, A. (2020). Chemically Modified Biosorbents and Their Role in the Removal of Emerging Pharmaceutical Waste in the Water System. *Water, 12,* 1551.

Adeyi, A.A., Jamil, S.N.A.M., Abdullah, L.C., Choong, T.S.Y., Lau, K.L., & Abdullah, M. (2019). Adsorptive Removal of Methylene Blue from Aquatic Environments Using Thiourea-Modified Poly(Acrylonitrile-*co*-Acrylic Acid). *Materials. 12*: 1734.

Adeyi, A.A., Jamil, S.N.A.M., Abdullah, L.C., & Choong, T.S.Y. (2019). Hydrophilic thiourea‑modified poly(acrylonitrile‑*co*‑acrylic acid) adsorbent: preparation, characterization, and dye removal performance. *Iranian Polymer Journal, 28(6),* 483–491.

Adeyi, A.A., Jamil, S.N.A.M., Abdullah, L.C., & Choong, T.S.Y. (2019). Adsorption of Malachite Green Dye from Liquid Phase Using Hydrophilic Thiourea-Modified Poly(acrylonitrile-*co*-acrylic acid): Kinetic and Isotherm Studies. *Journal of Chemistry, 2019,* 1–14.

Alkan, Ö., & Elmali, K. (2015). The Determination of the Factors Affecting Pharmaceutical Consumption in Respect to Provinces in Turkey. *Mediterranean Journal of Social Sciences*, *6,* 356-363.

Al-Odaini, N.A., Zakaria, M.P., Yaziz, M.I., Surif, S., & Abdulghani, M. (2013). The occurrence of human pharmaceuticals in wastewater effluents and surface water of Langat River and its tributaries, Malaysia. *International Journal of Environmental Analytical Chemistry*, *93(3),* 245-264.

Álvarez, S., Ribeiro, R.S., Gomes, H.T., Sotelo, J.L., & García, J. (2015). Synthesis of carbon xerogels and their application in adsorption studies of caffeine and diclofenac as emerging contaminants. *Chemical Engineering Research and Design, 45,* 229-238.

Andrade, J.R.D., Oliveira, M.F., Silva, M.G.C.D., & Vieira, M.G.A. (2018). Adsorption of Pharmaceuticals from Water and Wastewater Using Nonconventional Low-Cost Materials: A Review. *Industrial & Engineering Chemistry Research*, *57,* 3103–3127.

Ariffin, M., & Zakili, T.S.T. (2019). Household Pharmaceutical Waste Disposal in Selangor, Malaysia— Policy, Public Perception, and Current Practices. *Environmental Management*, *64(4),* 509-519.

Artioli, Y. (2008). Adsorption. *Encyclopedia of Ecology*, 60-6

Balasubramani, K., Sivarasajekar, N., & Naushad, M. (2020). Effective adsorption of antidiabetic pharmaceutical (metformin) from aqueous medium using graphene oxide nanoparticles: Equilibrium and statistical modelling. *Journal of Molecular Liquids, 301,* 112426.

Barczak, M., Dobrowolski, R., Borowski, P., & Giannakoudakis (2020). Pyridine-, thiol- and amine-functionalized mesoporous silicas for adsorptive removal of pharmaceuticals. *Microporous and Mesoporous Materials. 299,* 110132.

Barra Caracciolo A., Topp E., & Grenni P. (2015). Pharmaceuticals in the environment: biodegradation and effects on natural microbial communities. A review. *Journal of Pharmaceutical and Biomedical Analysis*, *106,* 25–36.

Behboudi, A., Jafarzadeh, Y., & Yegani, R. (2017). Polyvinyl chloride/polycarbonate blend ultrafiltration membranes for water treatment. *Journal of Membrane Science*, *534,* 18-24.

Bernal, V., Giraldo, L., & Moreno‑Piraján, J.C. (2019). Insight into adsorbate–adsorbent interactions between aromatic pharmaceutical compounds and activated carbon: equilibrium isotherms and thermodynamic analysis. *Adsorption*, *26,* 153-163.

Blanchard, G., Maunaye, M., & Martin, G. (1984). Removal of heavy metals from waters by means of natural zeolites. *Water Research*, *18(12),* 1501–1507.

Bound J.P., & Voulvoulis N. (2005). Household disposal of pharmaceuticals as a pathway for aquatic contamination in the United Kingdom. *Environmental Health Perspectives*, *113(12),* 1705–1711.

Braun, D., Eidam, N., & Leiß, D. (1991). FTIR studies of polar interactions in polymer blends. *Makromol Chem Macromol Symp*, *52,* 105–111.

Bringolf R.B., Heltsley R.M., Newton T.J., Eads C.B., Fraley S.J., Shea D., & Cope W.G. (2010). Environmental occurrence and reproductive effects of the pharmaceutical fluoxetine in native freshwater mussels. *Environmental Toxicology and Chemistry*, *29(6),* 1311–1318.

Briones, R.M., Sarmah, A.K., & Padhye, L.P. (2016). A global perspective on the use, occurrence, fate and effects of anti-diabetic drug metformin in natural and engineered ecosystems. *Environmental Pollution*, *219,* 1007–1020.

Briones, R.M., & Sarmah, A.K. (2018). Detailed sorption characteristics of the anti-diabetic drug metformin and its transformation product guanylurea in agricultural soils. *Science of the Total Environment*, *630,* 1258-1268.

Brodin T., Piovano S., Fick J., Klaminder J., Heynen M., & Jonsson M. (2014). Ecological effects of pharmaceuticals in aquatic systems – impacts through behavioural alterations. *Philosophical Transactions of the Royal Society B: Biological Siences*, *369(1656),* 20130580.

Brooks B.W., Chambliss C.K., Stanley J.K., Ramirez A., Banks K.E., Johnson R.D., & Lewis R.J. (2005). Determination of select antidepressants in fish from an effluent-dominated stream. *Environmental Toxicology and Chemistry*, *24(2),* 464–469.

Caldwell D.J., Mertens B., Kappler K., Senac T., Journel R., Wilson P., Meyerhoff R.D., Parke N.J., Mastrocco F., Mattson B., Murray-Smith R., Dolan D.G., Straub J.O., Wiedemann M., Hartmann A., & Finan D.S. (2016). A risk-based approach to managing active pharmaceutical ingredients in manufacturing effluent. *Environmental Toxicology and Chemistry*, *35(4),* 813–822.

Cantarella, M., Carroccio, S.C., Dattilo, S., Avolio, R., Castaldo, R., Puglisi, C., & Privitera, V. (2019). Molecularly imprinted polymer for selective adsorption of diclofenac from contaminated water. *Chemical Engineering Journal, 367,* 180–188.

Cardoso O., Porcher J.M., & Sanchez W. (2014). Factory-discharged pharmaceuticals could be a relevant source of aquatic environment contamination: review of evidence and need for knowledge. *Chemosphere*, *115,* 20–30.

Celiz M.D., Tso J., & Aga D.S. (2009). Pharmaceutical metabolites in the environment: analytical challenges and ecological risks. *Environmental Toxicology and Chemistry*, *28(12),* 2473–2484.

Chaudhary, V., & Sharma, S. (2019). Suspension polymerization technique: parameters affecting polymer properties and application in oxidation reactions. *Journal of Polymer Research*, *26,* 102.

Chauhan, M., Saini, V.K., & Suthar, S. (2020). Enhancement in selective adsorption and removal efficiency of natural clay by intercalation of Zr-pillars into its layered nanostructure. *Journal of Cleaner Production*, *258,* 120686.

Chauhan, M., Saini, V.K., & Suthar, S. (2019). Removal of pharmaceuticals and personal care products (PPCPs) from water by adsorption on aluminum pillared clay. *Journal of Porous Materials*, *27(2),* 283–293.

Chen, Y., Wang, F., Duan, L., Yang, H., & Gao, J. (2016). Tetracycline adsorption onto rice husk ash, an agricultural waste: Its kinetic and thermodynamic studies. *Journal of Molecular Liquids*, *222,* 487-494.

Chen, J.J., Ahmad, A.L., & Ooi, B.S. (2013). Poly(N-isopropylacrylamide-co-acrylic acid) hydrogels for copper ion adsorption: Equilibrium isotherms, kinetic and thermodynamic studies. *Journal of Environmental Chemical Engineering*, *1(3),* 339–348.

Cherik, D., & Louhab, K. (2017). A kinetics, isotherms and thermodynamic study of diclofenac adsorption using activated carbon prepared from olive stones. *Journal of Dispersion Science and Technology*, 39(6), 814-825.

Chien, S.H., & Clayton, W.R. (1980). Application of Elovich Equation to the Kinetics of Phosphate Release and Sorption in Soils. *Soil Science Society of America Journal*, *44(2),* 265–268.

Chularueangaksorn, P., Tanaka, S., Fujii, S., & Kunacheva, C. (2013). Regeneration and reusability of anion exchange resin used in perfluorooctane sulfonate removal by batch experiments. *Journal of Applied Polymer Science, 130*, 884–890.

Cimirro, N.F.G.M., Lima, E.C., Cunha, M.R., Dias, S.L.P., Thue, P.S., Mazzocato, A.C., Dotto, G.L., Gelesky, M.A., & Pavan, F.A. (2020). Removal of pharmaceutical compounds from aqueous solution by novel activated carbon synthesized from lovegrass (Poaceae). *Environmental Science and Pollution Research*, *27,* 21442–21454.

Coimbra, R.N., Calisto, V., Ferreira, C.I.A., Esteves, V.I., & Otero, M. (2019). Removal of pharmaceuticals from municipal wastewater by adsorption onto pyrolyzed pulp mill sludge. *Arabian Journal of Chemistry*, *12(8),* 3611–3620.

Crago, J., Bui, C., Grewal, S., & Schlenk, D. (2016). Age-dependent effects in fathead minnows from the anti-diabetic drug metformin. *General and Comparative Endocrinology*, *232,* 185-190.

Cui C.W., Ji S.L., & Ren H.Y. (2006). Determination of steroid estrogens in wastewater treatment plant of a controceptives producing factory. *Environmental Monitoring and Assessment*, *121(1– 3),* 409–419.

Cusioli. L.F., Quesada, H.B., Castro, A.L.D.B.P., Gomes, R.G., & Bergamasco, R. (2020). Development of a new low-cost adsorbent functionalized with iron nanoparticles for removal of metformin from contaminated water. *Chemosphere, 247,* 125852.

Dalahmeh, S., Björnberg, E., Elenström, A.-K., Niwagaba, C.B., & Komakech, A.J. (2020). Pharmaceutical pollution of water resources in Nakivubo wetlands and Lake Victoria, Kampala, Uganda. *Science of the Total Environment*, *710,* 136347.

Daughton, C.G. (2003). Cradle-to-cradle stewardship of drugs for minimizing their environmental disposition while promoting human health. II. Drug disposal, waste reduction, and future directions. *Environmental Health Perspectives, 111(5),* 775–785.

Davankov, V., & Tsyurupa, M. (1990). Structure and properties of hypercrosslinked polystyrene—the first representative of a new class of polymer networks. *Reactive Polymers, 13,* 27-42.

Davankov, V., Rogozhin, S., Semechkin, A., & Sachkova, T. (1973). Ligand-exchange chromatography of racemates. *Journal of Chromatography A, 82,* 359-365.

Ding J., Lu G., Li S., Nie Y., & Liu J. (2015). Biological fate and effects of propranolol in an experimental aquatic food chain. *Science of the Total Environment, 532,* 31–39.

Du B., Haddad S.P., Scott W.C., Chambliss C.K., & Brooks B.W. (2015). Pharmaceutical bioaccumulation by periphyton and snails in an effluent-dependent stream during an extreme drought. *Chemosphere*, *119,* 927–934.

Duarte, I.A., Reis-Santos, P., Novais, S.C., Rato, L.D., Lemos, M.F., Freitas, A., Pouca, A.S.V., Barbosa, J., Cabral, H.N., & Fonseca, V.F. (2020). Depressed, hypertense and sore: Long-term effects of fluoxetine, propranolol and diclofenac exposure in a top predator fish. *Science of the Total Environment*, *712,* 136564.

Eckenfelder, W. W. (2000). Industrial Water Pollution Control: Mc Graw Hill Book Company, New York.

El-Newehy, M. H., Alamri, A., & Al-Deyab, S. S. (2014). Optimization of amine-terminated polyacrylonitrile synthesis and characterization. *Arabian Journal of Chemistry*, *7(2),* 235-241.

Eslami, A., Chegini, Z.G., Khashij, M., Mehralian, M., & Hashemi, M. (2020). Removal of acetaminophen (ACT) from aqueous solution by using nanosilica adsorbent: experimental study, kinetic and isotherm modelling. *Pigment & Resin Technology*, *49,* 55-62.

Fan, L., Lu, Y., Yang, L.Y., Huang, F., & Ouyang, X.K. (2019). Fabrication of polyethylenimine-functionalized sodium alginate/cellulose nanocrystal/polyvinyl alcohol core–shell microspheres ((PVA/SA/CNC)@PEI) for diclofenac sodium adsorption. *Journal of Colloid and Interface Science*, *554,* 48-58.

Fontanals, N., Cortés, J., Galià, M., Marcé, R. M., Cormack, P. A. G., Borrull, F., & Sherrington, D. C. (2005). Synthesis of Davankov-Type Hypercrosslinked Resins Using Different Isomer Compositions of Vinylbenzyl Chloride Monomer, and Application in the Solid-Phase Extraction of Polar Compounds. *Journal of Polymer Science Part A: Polymer Chemistry*, *43(8),* 1718–1728.

Fontanals, N., Manesiotis, P., Sherrington, D. C., & Cormack, P. A. (2008). Synthesis of Spherical Ultra-High-Surface-Area Monodisperse Amphipathic Polymer Sponges in the Low-Micrometer Size Range. *Advanced Materials, 20(7),* 1298-1302.

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

Freitas, O., Figueiredo, S., Węgrzyn, A., Dańko, T., Stawiński, W., & Chmielarz, L. (2017). Acid-base treated vermiculite as high performance adsorbent: Insights into the mechanism of cationic dyes adsorption, regeneration, recyclability and stability studies. *Chemosphere*, *173,* 107–115.

Freundlich, H.M.F. (1906). Über die adsorption in lösungen. *Zeitschrift für Physikalische Chemie*, *57A*, 385-470.

Fu, C., Zhang, H., Xia, M., Lei, W., & Wang, F. (2020). The single/co-adsorption characteristics and microscopic adsorption mechanism of biochar-montmorillonite composite adsorbent for pharmaceutical emerging organic contaminant atenolol and lead ions. *Ecotoxicology and Environmental Safety*, *187,* 109763.

Fu, Z., & Huang, J. (2017). Polar hyper-cross-linked resin with abundant micropores/mesopores and its enhanced adsorption toward salicylic acid: Equilibrium, kinetics, and dynamic operation. *Fluid Phase Equilibria, 438,* 1–9.

Galicia-Aguilar, J.A., Santamaría-Juárez, J.D., López-Badillo, M., Sánchez-Cantú, M., & Varela-Caselis, J.L. (2017). Synthesis and characterization of AN/EGDMA-based adsorbents for phenol adsorption. *Reactive and Functional Polymers, 117,* 112–119.

Gan, Y., Chen, G., Sang, Y., Zhou, F., Man, R., & Huang, J. (2019). Oxygen-rich hyper-cross-linked polymers with hierarchical porosity for aniline adsorption. *Chemical Engineering Journal, 368*, 29–36.

Ghafari, M., Cui, Y., Alali, A., & Atkinson, J. D. (2019). Phenol adsorption and desorption with physically and chemically tailored porous polymers: Mechanistic variability associated with hyper-cross-linking and amination. *Journal of Hazardous Materials, 361,* 162–168.

Ghiorghita, C.A., Bucatariu, F., & Dragan, E.S. (2016). Sorption/release of diclofenac sodium in/from free-standing poly(acrylic acid)/poly(ethyleneimine) multilayer films. *Journal of Applied Polymer Science*, *133(31),* 43752.

Giannarelli, R., Aragona, M., Coppelli, A., & Prato, S.D. (2003). Reducing insulin resistance with metformin: the evidence today. *Diabetes & Metabolism*, *29.*

Gokmen, M.T., & Prez, F.E.D. (2012). Porous polymer particles—A comprehensive guide to synthesis, characterization, functionalization and applications. *Progress in Polymer Science, 37,* 365–405.

Grabicova K., Grabic R., Blaha M., Kumar V., Cerveny D., Fedorova G., & Randak T. (2015). Presence of pharmaceuticals in benthic fauna living in a small stream affected by effluent from a municipal sewage treatment plant. *Water Research, 72,* 145–153.

Guo, M., Shao, L., Du, Y., Qian, Z., Huang, T., & Tang, D. (2019). Microporous polymer based on the new compound “bi-(4-vinyl phenylquinoline) amide” for enrichment and quantitative determination of lamotrigine in rat and human serum. *Analytical and Bioanalytical Chemistry*, *411,* 3353-3360.

Guo, X., Yan, Z., Zhang, Y., Kong, X., Kong, D., Shan, Z., & Wang, N. (2017). Removal mechanisms for extremely high-level fluoroquinolone antibiotics in pharmaceutical wastewater treatment plants. *Environmental Science and Pollution Research*, *24,* 8769–8777.

Gupta, V.K., & Suhas (2009). Application of low-cost adsorbents for dye removal – A review. *Journal of Environmental Management*, *90,* 2313-2342.

Gusset, T., Trancart, J.-L., & Thévenot, D.R. (1986). Batch metal removal by peat. Kinetics and thermodynamics. *Water Research*, *20(1),* 21–26.

Hayasi, M., & Saadatjoo, N. (2017). Preparation of magnetic nanoparticles functionalized with poly (styrene-2-acrylamido-2-methyl propanesulfonic acid) as novel adsorbents for removal of pharmaceuticals from aqueous solutions. *Advances in Polymer Technology*, *37,* 1941–1953.

Hayati, B., Mahmoodi, N. M., & Maleki, A. (2015). Dendrimer-titania nanocomposite: Synthesis and dye-removal capacity. *Research on Chemical Intermediate, 41(6),* 3743-3757.

Heberer T. (2002). Tracking persistent pharmaceutical residues from municipal sewage to drinking water. *Journal of Hydrology*, *266,* 175–189.

Hemine, K., Skwierawska, A., Kernstein, A., & Kozłowska-Tylingo, K. (2020). Cyclodextrin polymers as efficient adsorbents for removing toxic non-biodegradable pimavanserin from pharmaceutical wastewaters. *Chemosphere, 250,* 126250.

Ho, Y.S. and McKay, G. (1999). Pseudo second order model for sorption processes. *Process Biochemistry, 34(5),* 451–465.

Huang, X., Liu, Y., Liu, S., Li, Z., Tan, X., Ding, Y., Zeng, G., Xu, Y., Zeng, W., & Zheng, B. (2016). Removal of metformin hydrochloride by *Alternanthera philoxeroides* biomass derived porous carbon materials treated with hydrogen peroxide. *RSC Advances, 6(83),* 79275-79284.

Hubetska, T., Kobylinska, N., & García, J.R. (2019). Efficient adsorption of pharmaceutical drugs from aqueous solution using a mesoporous activated carbon. *Adsorption, 26,* 251-266.

Hwang, K.S., Choi, W.J., Kim, J.-H., & Lee, J.-Y. (2015). Preparation of Hypercrosslinked Poly(DVB-VBC) Particles with High Surface Area and Structured Meso- and Micropores. *Macromolecular Research, 23,* 1051-1058.

Igberase, E., & Osifo, P. (2015). Equilibrium, kinetic, thermodynamic and desorption studies of cadmium and lead by polyaniline grafted cross-linked chitosan beads from aqueous solution. *Journal of Industrial and Engineering Chemistry, 26,* 340–347.

Ismail, N.A.H., Wee, S.Y., Haron, D.E.M., Kamarulzaman, N.H., & Aris, A.Z. (2020). Occurrence of endocrine disrupting compounds in mariculture sediment of Pulau Kukup, Johor, Malaysia. *Marine Pollution Bulletin, 150,* 110735.

Jackson, L.M., & Klerks, P.L. (2019). Impact of Long‑Term Exposure to 17α‑Ethinylestradiol in the Live‑Bearing Fish *Heterandria formosa. Archives of Environmental Contamination and Toxicology,* ***77****, 51–61.*

Jain, S., Chattopadhyay, S., Jackeray, R., & Singh, H. (2009). Surface modification of polyacrylonitrile fiber for immobilization of antibodies and detection of analyte. *Analytica Chimica Acta, 654(2),* 103-110.

Jayalakshmi, R., & Jeyanthi, J. (2019). Simultaneous removal of binary dye from textile effluent using cobalt ferrite-alginate nanocomposite : Performance and mechanism. *Microchemical Journal, 145,* 791–800.

Jeffries, K.M., Brander S.M., Britton M.T., Fangue N.A., & Connon R.E. (2015). Chronic exposure to low and high concentration of ibuprofen elicit different gene response patterns in a euryhaline fish. *Environmental Science and Pollution Research, 22(22),* 17397–17413.

Jelić, A., Gros, M., Petrović, M., Ginebreda, A., & Barceló, D. (2012). Occurrence and Elimination of Pharmaceuticals During Conventional Wastewater Treatment. *The Handbook of Environmental Chemistry Emerging and Priority Pollutants in Rivers*. 1-23.

Jelić A., Gros M., Ginebreda A., Cespedes-Sánchez R., Ventura F., Petrovic M., & Barcelo D. (2011). Occurrence, partition and removal of pharmaceuticals in sewage water and sludge during wastewater treatment. *Water Research, 45(3),* 1165–1176.

Jemutai-Kimosop, S., Orata, F., Shikuku, V.O. Okello, V.A., & Getenga, Z.M. (2020). Insights on adsorption of carbamazepine onto iron oxide modified diatomaceous earth: Kinetics, isotherms, thermodynamics, and mechanisms. *Environmental Research*, *180,* 108898.

Jose, J., John, M., & Mathew, B. (2003). Effect of the Nature of Crosslinking Agent on the Catalase-Like Activity of Polystyrene-Bound Glycine–Metal Complexes. *Journal of Macromolecular Science, Part A, 40,* 863–879.

Kafeenah, H.I.S., Osman, R., & Bakar, N.K.A. (2018). Disk solid-phase extraction of multi-class pharmaceutical residues in tap water and hospital wastewater, prior to ultra-performance liquid chromatographic-tandem mass spectrometry (UPLC-MS/MS) analyses. *RSC Advances*, *8(70),* 40358-40368.

Kajjumba, G.W., Emik, S., Öngen, A., Özcan, H.K., & Aydin, S. (2018). Modelling of Adsorption Kinetic Processes—Errors, Theory and Application. Sorption.

Kalgutkar A.S., Dalvie D.K., O'Donnell J.P., Taylor T.J., & Sahakian D.C. (2002). On the diversity of oxidative bioactivation reactions on nitrogen-containing xenobiotics. *Current Drug Metabolism, 3(4*), 379–424.

Kalumpha, M., Guyo, U., Zinyama, N.P., Vakira, F.M., & Nyamunda, B.C. (2019). Adsorptive potential of Zea mays tassel activated carbon towards the removal of metformin hydrochloride from pharmaceutical effluent. *International Journal of Phytoremediation*, *22(2),* 148-156.

Karmakar, S., Roy, D., Janiak, C., & De, S. (2019). Insights into multi-component adsorption of reactive dyes on MIL-101-Cr metal organic framework : Experimental and modeling approach, *Separation and Purification Technology, 215,* 259–275.

Khan, S.A., Siddiqui, M.F., & Khan, T.A. (2020). Synthesis of Poly(methacrylic acid)/Montmorillonite Hydrogel Nanocomposite for Efficient Adsorption of Amoxicillin and Diclofenac from Aqueous Environment: Kinetic, Isotherm, Reusability, and Thermodynamic Investigations. *ACS Omega*, *5,* 2843-2855.

Khazri, H., Ghorbel-Abid, I., Kalfat, R., & Trabelsi-Ayadi, M. (2017). Extraction of Clarithromycin and Atenolol by cuttlefish bone powder. *Environmental Technology*, *39,* 2662-2668.

Khazri, H., Ghorbel-Abid, I., Kalfat, R., & Trabelsi-Ayadi, M. (2017). Removal of ibuprofen, naproxen and carbamazepine in aqueous solution onto natural clay: equilibrium, kinetics, and thermodynamic study. *Applied Water Science*, *7,* 3031-3040.

Khetan S.K., & Collins T.J. (2007). Human pharmaceuticals in the aquatic environment: a challenge to Green Chemistry. *Chemical Reviews*, *107(6),* 2319–2364.

Kiani, G.R., Sheikhloie, H., & Arsalani, N. (2011). Heavy metal ion removal from aqueous solutions by functionalized polyacrylonitrile. *Desalination*, *269,* 266–270.

Kim, D., Lee, D. Y., Lee, K., & Choe, S. (2009). Effect of Crosslinking Agents on the Morphology of Polymer Particles Produced by One-Step Seeded Polymerization. *Macromolecular Research*, *17(4),* 250–258.

Kim, H., Lee, H., Kim, C.-M., & Jang, A. (2020). Enhancement of ozonation of seawater-based wastewater containing pharmaceutical compounds by total residual oxidants: Salinity, ammonia, and organic matter. *Chemosphere*, *259,* 127513.

Kong, L., Kadokami, K., Wang, S., Duong, H.T., & Chau, H.T.C. (2015). Monitoring of 1300 organic micro-pollutants in surface waters from Tianjin, North China. *Chemosphere*, *122,* 125–130.

Králik, M. (2014). Adsorption, chemisorption, and catalysis. *Chemical Papers*, *68,* 1625–1638.

Kyzas, G.Z., Nanaki, S.G., Koltsakidou, A., Papageorgiou, M., Kechagia, M., Bikiaris, D.N., & Lambropoulou, D.A. (2015). Effectively designed molecularly imprinted polymers for selective isolation of the antidiabetic drug metformin and its transformation product guanylurea from aqueous media. *Analytica Chimica Acta*, *866,* 27-40.

Lagergren S. (1898). About the theory of so-called adsorption of soluble substances. *Kungliga Svenska Vetenskapsakademiens Handlingar*, *24,* 1–39.

Lahti M., Brozinski J.M. Jylhä A. Kronberg L., & Oikari A. (2011). Uptake from water, biotransformation, and biliary excretion of pharmaceuticals by rainbow trout. *Environmental Toxicology and Chemistry*, *30(6),* 1403–1411.

Langford K., & Thomas K.V. (2011). Input of selected human pharmaceutical metabolites into the Norwegian aquatic environment. *Journal of Environmental Monitoring*, *13,* 416–421.

Langmuir, I. (1918). The adsorption of gases on plane surfaces of glass, mica and platinum. *Journal of the American Chemical Society*. *40*, 1361-1403.

Larsson D.G., de Pedro C., & Paxeus N. (2007). Effluent from drug manufactures contains extremely high levels of pharmaceuticals. *Journal of Hazardous Materials*, *148(3),* 751–755.

Larsson, D.G.J. (2014). Pollution from drug manufacturing: review and perspectives. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *369,* 20130571.

Lee, J.W., Shin, Y.J., Kim, H., Kim, H., Kim, J., Min, S.A., Kim, P., Yu, S.D., & Park, K. (2019). Metformin-induced endocrine disruption and oxidative stress of *Oryzias latipes* on two-generational condition. *Journal of Hazardous Materials*, *367,* 171-181.

Leshchinskaya, A., Ezhova, N., & Pisarev, O. (2016). Synthesis and characterization of 2-hydroxyethyl methacrylate-ethylene glycol dimethacrylate polymeric granules intended for selective removal of uric acid. *Reactive and Functional Polymers, 102*, 101–109.

Leung, H.W., Jin, L., Wei, S., Tsui, M.M.P., Zhou, B., Jiao, L., Cheung, P.C., Chun, Y.K., Murphy, M.B., & Lam, P.K.S. (2013). Pharmaceuticals in Tap Water: Human Health Risk Assessment and Proposed Monitoring Framework in China. *Environmental Health Perspectives*, *121(7),* 839-846.

Li, G., Meng, X., Wang, J., Wang, Q., Zhou, J., Wang, C., Wu, Q., & Wang, Z. (2020). A low-cost and high-efficiency carbazole-based porous organic polymer as a novel sorbent for solid-phase extraction of triazine herbicides in vegetables. *Food Chemistry*, *309,* 125618.

Li, G., Zhang, B., Yan, J., & Wang, Z. (2016). The cost-effective synthesis of furan- and thienyl-based microporous polyaminals for adsorption of gases and organic vapors. *Chemical Communications, 52,* 1143-1146.

Li W., Shi Y., Gao L., Liu J., & Cai Y. (2012). Investigation of antibiotics in mollusks from coastal waters in the Bohai Sea of China. *Environmental Pollution, 162,* 56–62.

Li, W.H., & Stöver, H.D.H. (2000). Monodisperse Cross-Linked Core-Shell Polymer Microspheres by Precipitation Polymerization. *Macromolecules, 33,* 4354–4360.

Li, Y., Wang, Y., He, L., Meng, L., Lu, H., & Li, X. (2020). Preparation of poly(4-vinylpyridine)-functionalized magnetic Al-MOF for the removal of naproxen from aqueous solution. *Journal of Hazardous Materials*, *383,* 121144.

Li, Y., Taggart, M.A., McKenzie, C., Zhang, Z., Lu, Y., Pap, S., & Gibb, S. (2019). Utilizing low-cost natural waste for the removal of pharmaceuticals from water: Mechanisms, isotherms and kinetics at low concentrations. *Journal of Cleaner Production*, *227,* 88-97.

Li, X., Ji, M., Nghiem, L.D., Zhao, Y., Liu, D., Yang, Y., Wang, Q., Trinh, Q.T., Vo, D.-V.N., Pham, V.Q., & Tran, N.H. (2020). A novel red mud adsorbent for phosphorus and diclofenac removal from wastewater. *Journal of Molecular Liquids*, *303,* 112286.

Liu, J.-L., & Wong, M.-H. (2013). Pharmaceuticals and personal care products (PPCPs): A review on environmental contamination in China. *Environment International*, *59,* 208-224.

Liu, D., Chen, H., Yin, P., Ji, N., Zong, G., & Qu, R. (2011). Synthesis of polyacrylonitrile by single-electron transfer-living radical polymerization using Fe(0) as catalyst and its adsorption properties after modification. *Journal of Polymer Science Part A: Polymer Chemistry, 49(13),* 2916-2923.

Liu J., Lu G., Wang Y., Yan Z., Yang X., Ding J., & Jiang Z. (2014). Bioconcentration, metabolism, and biomarker responses in freshwater fish Carassius auratus exposed to roxithromycin. *Chemosphere, 99,* 102–108.

Liu, X., Chen, H., Wang, C., Qu, R., Ji, C., Sun, C., & Zhang, Y. (2010). Synthesis of porous acrylonitrile/methyl acrylate copolymer beads by suspended emulsion polymerization and their adsorption properties after amidoximation. *Journal of Hazardous Materials*, *175,* 1014–1021.

Liu, Z., Chen, G., Zhou, F., & Huang, J. (2019). Imidazolium Salt Incorporated Poly(N ‑vinylimidazole-co-ethylene glycol dimethacrylate) for Efficient Adsorption of Congo Red and Hg^{2+} from Aqueous Solution. *Journal of Chemical & Engineering Data*, *64(6),* 2627-2633.

Lu, Y., Wang, Z., Ouyang, X., Ji, C., Liu, Y., Huang, F., & Yang, L.-Y. (2020). Fabrication of cross-linked chitosan beads grafted by polyethylenimine for efficient adsorption of diclofenac sodium from water. *International Journal of Biological Macromolecules, 145,* 1180-1188.

Łukaszewicz P., Maszkowska J., Mulkiewicz E., Kumirska J., Stepnowski P., & Caban M., (2016). Impact of Veterinary Pharmaceuticals on the Agricultural Environment: A Re-inspection. *Review of Environmental Contamination and Toxicology*, *243,* 89–148.

Marcos-Hernández, M., & Villagrán, D. (2019). Mesoporous Composite Nanomaterials for Dye Removal and Other Applications. *Composite Nanoadsorbents*, 265–293.

Mattson, J. S., & Mark H. B. (1971). Activated Carbon Surface Chemistry and Adsorption from Solution, Marcell Dekker, New York.

Mellah, A., & Harik, D. (2020). Removal Pharmaceutical Pollutants by Adsorption Competitive using Powdered Activated Carbon CAP (F400). *Journal of Environmental Treatment Techniques*, *8,* 336-345.

Mendoza A., Aceña J., Pérez S., López de Alda M., Barceló D., Gil A., & Valcárcel Y. (2015). Pharmaceuticals and iodinated contrast media in a hospital wastewater: A case study to analyse their presence and characterise their environmental risk and hazard. *Environmental Research*, *140,* 225–241.

Menéndez, J.A., Arenillas, A., Fidalgo, B., Fernández, Y., Zubizarreta, L., Calvo, E.G., & Bermúdez, J.M. (2010). Microwave heating processes involving carbon materials. *Fuel Processing Technology*, *91,* 1-8.

Mikulic, M. (2020). Pharmaceutical market: worldwide revenue 2001-2019.

Miossec, C., Mille, T., Lanceleur, L., & Monperrus, M. (2020). Simultaneous determination of 42 pharmaceuticals in seafood samples by solvent extraction coupled to liquid chromatography–tandem mass spectrometry. *Food Chemistry*, *322,* 126765.

Mirzaei, A., Chen, Z., Haghighat, F., & Yerushalmi, L. (2017). Removal of pharmaceuticals from water by homo/heterogonous Fenton-type processes – A review. *Chemosphere*, *174,* 665-688.

Mishra, A., Sharma, S. and Gupta, B. (2011). Studies on the Amidoximation of Polyacrylonitrile Films: Influence of Synthesis Conditions. *Journal of Applied Polymer Science*, *121(5),* 2705-2709.

Momina, Shahadat, M., & Isamil, S. (2018). Regeneration performance of clay-based adsorbents for the removal of industrial dyes: a review. *RSC Advances*, *8,* 24571-24587.

Moreira, I.S., Bessa, V.S., Murgolo, S., Piccirillo, C., Mascolo, G., & Castro, P.M.L. (2018). Biodegradation of Diclofenac by the bacterial strain *Labrys portucalensis* F11. *Ecotoxicology and Environmental Safety*, *152,* 104-113.

Moral-Rodriguez, A.I., Leyva-Ramos, R., Carrasco-Marín, F., Bautista-Toledo, M.I., & Pérez-Cadenas, A.F. (2020). Adsorption of Diclofenac from Aqueous Solution onto Carbon Xerogels: Effect of Synthesis Conditions and Presence of Bacteria. *Water, Air, & Soil Pollution*, *231(1),* 17.

Mouchtari, E.M.E., Daou, C., Rafqah, S., Najjar, F., Anane, H., Piram, A., Hamade, A., Briche, S., & Wong-Wah-Chung, P. (2020). TiO_2 and activated carbon of *Argania Spinosa* tree nutshells composites for the adsorption photocatalysis removal of pharmaceuticals from aqueous solution. *Journal of Photochemistry & Photobiology A: Chemistry*, *388,* 112183.

Narbaitz, R.M., & Karimi-Jashni, A. (2009). Electrochemical regeneration of granular activated carbons loaded with phenol and natural organic matter. *Environmental Technology*, *30,* 27-36.

Nariyan, E., Aghababaei, A., & Sillanpä ä, M. (2017). Removal of pharmaceutical from water with an electrocoagulation process; effect of various parameters and studies of isotherm and kinetic. *Separation and Purification Technology*, *188,* 266-281.

Nasir, F.A.M., Praveena, S.M., & Aris, A.Z. (2019). Public awareness level and occurrence of pharmaceutical residues in drinking water with potential health risk: A study from Kajang (Malaysia). *Ecotoxicology and Environmental Safety*, *185,* 109681.

Niaei, H. A., & Rostamizadeh, M. (2020). Adsorption of metformin from an aqueous solution by Fe-ZSM-5 nano-adsorbent: Isotherm, kinetic and thermodynamic studies. *Journal of Chemical Thermodynamics*, *142,* 106003.

Niemuth, N.J., & Klaper, R.D. (2015). Emerging wastewater contaminant metformin causes intersex and reduced fecundity in fish. *Chemosphere*, *135*, 38-45.

Niu, X., Zheng, L., Zhou, J., Dang, Z., & Li, Z. (2014). Synthesis of an adsorbent from sugarcane bagass by graft copolymerization and its utilization to remove Cd (II) ions from aqueous solution. *Journal of the Taiwan Institute of Chemical Engineers, 45*, 2557–2564.

Norhayati, A., Zuhaili, Y.M., & Rabiatuladawiah, M. (2018). Synthesis and characterization of poly(HEMA-*co*-EGDMA-*co*-VBC) by modified suspension polymerization: Effects of polymerization parameters reaction on chemical and thermal properties of polymer. *Materials Today: Proceedings, 5*, 22010–22019.

N'diaye, A.D., & Kankou, M.S.A. (2020). Sorption of Aspirin from Aqueous Solutions using Rice Husk as Low Cost Sorbent. *Journal of Environmental Techniques*, *8,* 1-5.

N'diaye, A.D., Bollahi, M.A., & Kankou, M.S.A. (2019). Sorption of paracetamol from aqueous solution using groundnut shell as a low cost sorbent. *Journal of Materials and Environmental Sciences*, *10,* 553-562.

Okoli, C.P., & Ofomaja, A.E. (2019) Development of sustainable magnetic polyurethane polymer nanocomposite for abatement of tetracycline antibiotics aqueous pollution: Response surface methodology and adsorption dynamics *Journal of Cleaner Production*, *217,* 42–55.

Omar, T.F.T., Aris, A.Z., Yusoff, F.M., & Mustafa, S. (2018). Risk assessment of pharmaceutically active compounds (PhACs) in the Klang River estuary, Malaysia. *Environmental Geochemistry and Health*, *41(1),* 211-223.

Orona-Návar, C., García-Morales, R., Rubio-Govea, R., Mahlknecht, J., Hernandez-Aranda, R.I., Ramírez, J.G., Nigam, K.D.P., & Ornelas-Soto, N. (2018). Adsorptive removal of emerging pollutants from groundwater by using modified titanate nanotubes. *Journal of Environmental Chemical Engineering*, *6(4),* 5332–5340.

Padmaja, K., Cherukuri, J., & Reddy, M.A. (2020). A comparative study of the efficiency of chemical coagulation and electrocoagulation methods in the treatment of pharmaceutical effluent. *Journal of Water Process Engineering*, *34,* 101153.

Parashar, A., Sikarwar, S., & Jain, R. (2020). Removal of pharmaceuticals from wastewater using magnetic iron oxide nanoparticles (IOPs). *International Journal of Environmental Analytical Chemistry,* 1-7.

Patiño-Herrera, R., Louvier-Hernández, J.F., Escamilla-Silva, E.M., Chaumel, J., Escobedo, A.G.P., & Pérez, E. (2019). Prolonged release of metformin by SiO_2 nanoparticles pellets for type II diabetes control. *European Journal of Pharmaceutical Sciences, 131,* 1-8.

Pereira, D., Rocha, L.S., Gil, M.V., Otero, M., Silva, N.J.O., Esteves, V.I., & Calisto, V. (2020). In situ functionalization of a cellulosic-based activated carbon with magnetic iron oxides for the removal of carbamazepine from wastewater. *Environmental Science and Pollution Research.*

Phonsiri, V., Choi, S., Nguyen, C., Tsai, Y.L., Coss, R., & Kurwadkar, S. (2019). Monitoring occurrence and removal of selected pharmaceuticals in two different wastewater treatment plants. *SN Applied Sciences, 1,* 798.

Piccin, J.S., Gomes, C.S., Feris, L.A., & Gutterres, M. (2012). Kinetics and isotherms of leather dye adsorption by tannery solid waste. *Chemical Engineering Journal*, *183,* 30–38.

Pinnavaia, T.J. (1983). Intercalated Clay Catalysts. *Science*, *220,* 365-371.

Pires, B.C., Dutra, F.V.A., & Borges, K.B. (2019). Synthesis of mesoporous magnetic polypyrrole and its application in studies of removal of acidic, neutral, and basic pharmaceuticals from aqueous medium. *Environmental Science and Pollution Research*, 27, 6488-6504.

Praneeth, K. (2014). Synthesis and characterization of novel polymeric membranes for water purification and effluents treatment. RMIT University, Australia.

Praveena, S.M., Rashid, M.Z.M., Nasir, F.A.M., Yee, W.S., & Aris, A.Z. (2019). Occurrence and potential human health risk of pharmaceutical residues in drinking water from Putrajaya (Malaysia). *Ecotoxicology and Environmental Safety*, *180,* 549-556.

Praveena, S.M., Shaifuddin, S.N.M., Sukiman, S., Nasir, F.A.M., Hanafi, Z., Kamarudin, N., Ismail, T.H.T., & Aris, A.Z. (2018). Pharmaceuticals residues in selected tropical surface water bodies from Selangor (Malaysia): Occurrence and potential risk assessments. *Science of the Total Environment*, *642,* 230-240.

Puckowski A., Mioduszewska K., Łukaszewicz P., Borecka M., Caban M., Maszkowska J., & Stepnowski P. (2016). Bioaccumulation and analytics of pharmaceutical residues in the environment: A review. *Journal of Pharmaceutical Biomedical Analysis, 127,* 232–255.

Qiu, H., Lv, L., Pan, B., Zhang, Q., Zhang, W., & Zhang, Q. (2009). Critical review in adsorption kinetic models. *Journal of Zhejiang University Science A*, 10(5), 716–724.

Queiroz, E.A.I.F., Puukila, S., Eichler, R., Sampaio, S.C., Forsyth, H.L., Lees, S.J., Barbosa, A.M., Dekker, R.F.H., Fortes, Z.B., & Khaper, N. (2014). Metformin Induces Apoptosis and Cell Cycle Arrest Mediated by Oxidative Stress, AMPK and FOXO3a in MCF-7 Breast Cancer Cells. *PLoS ONE 9*.

Rajapaksha, A.U., Premarathna, K.S.D., Gunarathne, V., Ahmed, A. and Vithanage, M. (2019). Sorptive removal of pharmaceutical and personal care products from water and wastewater. *Pharmaceuticals and Personal Care Products: Waste Management and Treatment Technology*. 213–238.

Ranjbari, S., Tanhaei, B., Ayati, A., Khadempir, S., & Sillanpää, M. (2020). Efficient tetracycline adsorptive removal using tricaprylmethylammonium chloride conjugated chitosan hydrogel beads: Mechanism, kinetic, isotherms and thermodynamic study. *International Journal of Biological Macromolecules, 155,* 421-429.

Ravi, S., Choi, Y., & Choe, J.K. (2020). Novel phenyl-phosphate-based porous organic polymers for removal of pharmaceutical contaminants in water. *Chemical Engineering Journal*, *379,* 122290.

Rena, G., Pearson, E.R., & Sakamoto, K. (2013). Molecular mechanism of action of metformin: old or new insights?. *Diabetologia, 56,* 1898–1906.

Roslan, N.A., Abdullah, N., & Abidin, S.Z. (2019). The synthesis of sulphonated hypercrosslinked exchange resin for free fatty acid esterification. *Comptes Rendus Chimie*, *22,* 761-770.

Rzymski, P., Drewek, A., & Klimaszyk, P. (2017). Pharmaceutical pollution of aquatic environment: an emerging and enormous challenge. *Limnological Review, 17,* 97–107.

Santos, P.R.D.O.D., Costa, M.J., Santos, A.C.A.D., Silva-Zacarín, E.C., & Nunes, B. (2020). Neurotoxic and respiratory effects of human use drugs on a Neotropical fish species, *Phalloceros harpagos*. *Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology*, *230,* 108683.

Sclavons, M., Laurent, M., Devaux, J., & Carlier, V. (2005). Maleic anhydride-grafted polypropylene: FTIR study of a model polymer grafted by ene-reaction. *Polymer*, 8062–8067.

Shi, Q., Sun, H., Yang, R., Zhu, Z., Liang, W., Tan, D., Yang, A., Li, A., & Deng, W. (2015). Synthesis of conjugated microporous polymers for gas storage and selective adsorption. *Journal of Materials Science, 50,* 6388-6394.

Silva, B., Martins, M., Rosca, M., Rocha, V., Lago, A., Neves, I.C., & Tavares, T. (2020). Waste-based biosorbents as cost-effective alternatives to commercial adsorbents for the retention of fluoxetine from water. *Separation and Purification Technology*, *235,* 116139.

Sim W.J., Lee J.W., Lee E.S., Shin S.K., Hwang S.R., & Oh J.E. (2011). Occurrence and distribution of pharmaceuticals in wastewater from households, livestock farms, hospitals and pharmaceutical manufactures. *Chemosphere*, *82(2),* 179–186.

Soares, S.F., Fernandes, T., Sacramento, M., Trindade, T., & Daniel-da-Silva, A.L. (2019). Magnetic quaternary chitosan hybrid nanoparticles for the efficient uptake of diclofenac from water. *Carbohydrate Polymers*, *203,* 35-44.

Soler, P., Solé, M., Bañón, R., García-Galea, E., Durfort, M., Matamoros, V., Bayona, J.M., & Vinyoles, D. (2019). Effects of industrial pollution on the reproductive biology of *Squalius laietanus* (Actinopterygii, Cyprinidae) in a Mediterranean stream (NE Iberian Peninsula). *Fish Physiology and Biochemistry*, *46(1),* 247-264.

Son, D.-J., Kim, W.-Y., Jung, B.-R., Chang, D., & Hong, K.-H. (2020). Pilot-scale anoxic/aerobic biofilter system combined with chemical precipitation for tertiary treatment of wastewater. *Journal of Water Process Engineering*, *35,* 101224.

Subri, N.N.S., Cormack, P.A.G., Jamil, S.N.A.M., Abdullah, L.C., & Daik, R. (2018). Synthesis of poly(acrylonitrile-*co*-divinylbenzene-*co*-vinylbenzyl chloride)-derived hypercrosslinked polymer microspheres and a preliminary evaluation of their potential for the solid-phase capture of pharmaceuticals. *Journal of Applied Polymer Science, 135,* 45677.

Sura S., Degenhardt D., Cessna A.J., Larney F.J., Olson A.F., & McAllister T.A. (2015). Transport of three veterinary anti- microbials from feedlot pens via simulated rainfall run-off. *Science of the Total Environment*, *521–522,* 191–199.

Tam, N.T.M., Liu, Y., Bashir, H., Yin, Z., He, Y., & Zhou, X. (2019). Efficient Removal of Diclofenac from Aqueous Solution by Potassium Ferrate-Activated Porous Graphitic Biochar: Ambient Condition Influences and Adsorption Mechanism. *International Journal of Environmental Research and Public Health*, *17(1),* 291.

Tan, L., & Tan, B. (2017). Hypercrosslinked porous polymer materials: design, synthesis, and applications. *Chemical Society Reviews, 46(11),* 3481-3481.

Tang, Y., Hong, C., He, X., & Ren, K. (2020). Kinetic and thermodynamic analysis of adsorption of naproxen by activated sludge. *IOP Conference Series: Earth and Environmental Science, 446,* 032017.

Tanwar, P.S., Kaneko-Tarui, T., Zhang, L. and Teixeira, J.M. (2012). Altered LKB1/AMPK/TSC1/TSC2/mTOR signaling causes disruption of Sertoli cell polarity and spermatogenesis. *Human Molecular Genetics*, *21,* 4394–4405.

Ternes T.A., Joss A., & Siegrist H. (2004). Scrutinizing pharmaceuticals and personal care products in wastewater treatment. *Environmental Science and Technology*, *38(20),* 392–399.

Thai, P.K., Ky, L.X., Binh, V.N., Nhung, P.H., Nhan, P.T., Hieu, N.Q., Dang, N.T., Tam, N.K.B., & Anh, N.T.K. (2018). Occurrence of antibiotic residues and antibiotic-resistant bacteria in effluents of pharmaceutical manufacturers and other sources around Hanoi, Vietnam. *Science of the Total Environment*, *645,* 393–400.

Tiwari, D., Lalhriatpuia, C., & Lee, S.M. (2015). Hybrid materials in the removal of diclofenac sodium from aqueous solutions: Batch and column studies. *Journal of Industrial and Engineering Chemistry*, *30,* 167-173.

Tomul, F., Arslan, Y., Başoğlu, F.T., Babuçcuoğlu, Y., & Tran, H.N. (2019). Efficient removal of anti-inflammatory from solution by Fe-containing activated carbon: Adsorption kinetics, isotherms, and thermodynamics. *Journal of Environmental Management*, *238,* 296-306.

Toudeshki, R.M., Dadfarnia, S., & Shabani, A.M.H. (2019). Surface molecularly imprinted polymer on magnetic multi-walled carbon nanotubes for selective recognition and preconcentration of metformin in biological fluids prior to its sensitive chemiluminescence determination: Central composite design optimization. *Analytica Chimica Acta, 1089,* 78–89.

Tran, T.V., Nguyen, D.T.C., Le, H.T.N., 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. *Journal of Environmental Sciences, 93,* 137–150.

Tran, H.N., Tomul, F., Ha, N.T.H., Nguyen, D.T., Lima, E.C., Le, G.T., Chang, C.-T., Masindi, V., & Woo, S.H. (2020). Innovative spherical biochar for pharmaceutical removal from water: Insight into adsorption mechanism. *Journal of Hazardous Materials*, *394,* 122255.

Tsyurupa, M., & Davankov, V. (2006). Porous structure of hypercrosslinked polystyrene: State-of-the-art mini-review. *Reactive and Functional Polymers, 66(7),* 768-779.

Tsyurupa, M., & Davankov, V. (2002). Hypercrosslinked polymers: basic principle of preparing the new class of polymeric materials. *Reactive and Functional Polymers, 53(2-3),* 193-203.

Urban, J., Svec, F., & Fréchet, J. M. (2010). Efficient Separation of Small Molecules Using a Large Surface Area Hypercrosslinked Monolithic Polymer Capillary Column. *Analytical Chemistry, 82,* 1621-1623.

Uzunova, S., Uzunov, I., & Angelova, D. (2013). Liquid-phase sorption of oil by carbonized rice husks: impact of grain size distribution on the sorption kinetics. *Journal of Chemical Technology and Metallurgy*, *48(5),* 505-512.

Vijayaraghavan, K., & Yun, Y.S. (2008). Bacterial biosorbents and biosorption. *Biotechnology Advances*, *26,* 266-291.

Viollet, B., Guigas, B., Garcia, N.S., Leclerc, J., Foretz, M., & Andreelli, F. (2012). Cellular and molecular mechanisms of metformin: an overview. *Clinical Science*, *122,* 253–270.

Wang, J., & Wang, S. (2016). Removal of pharmaceuticals and personal care products (PPCPs) from wastewater: A review. *Journal of Environmental Management*, *182,* 620-640.

Wang, T., Wang, N., Liu, Z., Dai, J., & Fei, Z. (2018). Comparative study of adsorption for *m*-phenylenediamine in aqueous solution onto chemically modified resins. *Journal of Applied Polymer Science*, *136(5),* 47378.

Wang, X., He, J., & Huang, J. (2019). Amino-modified hyper-cross-linked polymers with hierarchical porosity for adsorption of salicylic acid from aqueous solution. *Journal of Chemical Thermodynamics, 131*, 1–8.

Wang, X., Zhang, T., Huo, J., Huang, J., & Liu, Y.N. (2017). Tunable porosity and polarity of polar post-cross-linked resins and selective adsorption. *Journal of Colloid and Interface Science, 487,* 231–238.

Wang, R., Zhang, Y., Ma, G., & Su, Z. (2006). Preparation of uniform poly(glycidyl methacrylate) porous microspheres by membrane emulsification–polymerization technology. *Journal of Applied Polymer Science, 102,* 5018–5027.

Weber, W.J. (1984). Evolution of a Technology. *Journal of Environmental Engineering, 110(5),* 899–917.

Weber, W.J., & Morris, J.C. (1963). Kinetics of Adsorption on Carbon from Solution. *Journal of Sanitary Engineering Division ASCE*, *89(2),* 31–59.

Wee, S.Y., Haron, D.E.M., Aris, A.Z., Yusoff, F.M., & Praveena, S.M. (2020). Active pharmaceutical ingredients in Malaysian drinking water: consumption, exposure, and human health risk. *Environmental Geochemistry and Health*.

Wei, X., Xu, X., Li, C., Wu, J., Chen, J., Lv, B., & Wang, J. (2020). Removal of Pharmaceuticals and Personal Care Products in Aquatic Environment by Membrane Technology. *Environmental Chemistry for a Sustainable World Membranes for Environmental Applications*. 177–242.

Wernke, G., Shimabuku-Biadola, Q.L., Santos, T.R.T.D., Silva, M.F., Fagundes-Klen, M.R., & Bergamasco, R. (2020). Adsorption of cephalexin in aqueous media by graphene oxide: kinetics, isotherm, and thermodynamics. *Environmental Science and Pollution Research, 27,* 4725-4736.

Wilkinson, J., Boxall, A., & Kolpin, D. A. (2019). Novel Method to Characterise Levels of Pharmaceutical Pollution in Large-Scale Aquatic Monitoring Campaigns. *Applied. Sciences, 9(7),* 1368.

Wong, C.-W., Barford, J.P., Chen, G., & McKay, G. (2014). Kinetics and equilibrium studies for the removal of cadmium ions by ion exchange resin. *Journal of Environmental Chemical Engineering*, *2(1),* 698–707.

Wu, F.-C., Tseng, R.-L., & Juang, R.-S. (2009). Characteristics of Elovich equation used for the analysis of adsorption kinetics in dye-chitosan systems. *Chemical Engineering Journal*, *150,* 366–373.

Yahya, M.Z., & Abdullah, N. (2017). Preparation and Characterization of Hypercrosslinked Poly (HEMA-*co*-EGDMA-*co*-VBC). *Indian Journal of Science and Technology, 10*, 1–9.

Yuan, H.G., Kalfas, G., & Ray, W.H. (1991). Suspension Polymerization. *Journal of Macromoecular Science, Part C: Polymer Reviews, 31*, 215–299.

Yu, W., Sun, W., Xu, C., Wang, C., Jia, Y., Qin, X., Xie, C., Yu, S., & Xian, M. (2018). Effective adsorption toward p-aminobenzoic acid from aqueous solution by a L-malic acid modified hyper-crosslinked resin: Equilibria and kinetics. *Journal of the Taiwan Institute of Chemical Engineers, 80*, 105–112.

Zaied, B.K., Rashid, M., Nasrullah, M., Zularisam, A.W., Pant, D., & Singh, L. (2020). A comprehensive review on contaminants removal from pharmaceutical wastewater by electrocoagulation process. *Science of the Total Environment*, 138095.

Zhang, T., Zhou, F., Huang, J., & Man, R. (2018). Ethylene glycol dimethacrylate modified hyper-cross-linked resins: Porogen effect on pore structure and adsorption performance. *Chemical Engineering Journal*, *339,* 278–287.

Zhang, T., & Huang, J. (2017). Tunable synthesis of the polar modified hyper-cross-linked resins and application to the adsorption. *Journal of Colloid and Interface Science, 505*, 383–391.

Zheng, J., He, X., Cai, C., Xiao, J., Liu, Y., Chen, Z., Pan, B., & Lin, X. (2020). Adsorption isotherm, kinetics simulation and breakthrough analysis of 5-hydroxymethylfurfural adsorption/desorption behavior of a novel polar-modified post-cross-linked poly(divinylbenzene-*co*-ethylene glycol dimethacrylate) resin. *Chemosphere*, *239,* 124732.

Zheng, S., Li, X., Zhang, X., Wang, W., & Yuan, S. (2017). Effect of inorganic regenerant properties on pharmaceutical adsorption and desorption performance on polymer anion exchange resin. *Chemosphere*, *182,* 325-331.

Zhou, F., Man, R., & Huang, J. (2018). Alkoxy-Modified Hyper-Cross-Linked Polymers with Hierarchical Porosity and Their Adsorption of Salicylic Acid from Aqueous Solution. *Industrial & Engineering Chemistry Research*, *57(37),* 12420–12428.

Zhou, L., Qu, Z.G., Ding, T., & Miao, J.Y. (2016). Lattice Boltzmann simulation of the gas-solid adsorption process in reconstructed random porous media. *Physical Review E*, *93(4).*

Zhu, S.Z., Liu, Y.G., Liu, S.B., Zeng, G.M., Jiang, L.H., Tan, X.F., Zhou, L., Zeng, W., Li, T.T., & Yang, C.P. (2017). Adsorption of emerging contaminant metformin using grapheme oxide. *Chemosphere*, *179,* 20–28.

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LIST OF PUBLICATIONS

Shaipulizan, N.S., Jamil, S.N.A.M., Kamaruzaman, S., Subri, N.N.S., Adeyi, A.A., Abdullah, A.H. and Abdullah, L.C. (2020). Preparation of Ethylene Glycol Dimethacrylate (EGDMA)-Based Terpolymer as Potential Sorbents for Pharmaceuticals Adsorption. *Polymers*, *12*, 423.

Shaipulizan, N.S., Jamil, S.N.A.M., Abdullah, L.C., Yaw, T.C.S., Kamaruzaman, S., Subri, N.N.S. and Othman, N. (2020). Hypercrosslinked poly(AN-*co*-EGDMA-*co*-VBC): synthesis via suspension polymerization, characterizations and potential to adsorb diclofenac and metformin from aqueous solution. *Colloid and Polymer Science*, *298*, 1649-1667.

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