Original Research Article

J. Funct. Mater. Biomol. 4(2) (2020) pp 391 – 398

SACRED HEART RESEARCH PUBLICATIONS

Journal of Functional Materials and Biomolecules

Journal homepage: www.shcpub.edu.in

ISSN: 2456-9429

A comprehensive review on Nano-confined and Developmental Nanowood Materials for Water Purification Process

V. Ragul[1] and M. I. Niyas Ahamed[*]

Received on 16 October 2020, accepted on 18 December 2020,
Published online on 31 December 2020

Abstract

The wood materials are dynamically designed with extraordinary characteristics for numerous application aspects. The simplified cutting edged nano biomaterials transform with the cheap, cost effective and easily available woods are considered as updated and emerged material which is having its determined life time, structural property, and effective functions to the alternative resource for different kinds of polymers, plastics and metals. The present model expresses how the innovative nano wood materials have been developed and implemented in contaminated water in different parameters with effective functionality were described and discussed. The proper arrangement with hierarchical structures were introduced for bioremediation of contaminated water by modified or unmodified either top down or bottom up production of water filters with energy efficient desalination, catalytic activity, energy investment, resource recovery and environmental cleanups were discussed. The investigation offers, nascent but highly promising field to encourage research and development. Once the tree is harvested and used, it is ultimately understood that enhanced wood materials will provide a great impact in the circular water economy.

Keywords: Bioremediation; Desalination; Wood materials; nano wood

1 Introduction

All the existing creatures start from adequate and effective water, which act as a dynamic element in the biological system. The consideration offers to the water security for worldwide is wellbeing and monetary enhancement for guaranteeing pledge against water-borne contamination and water-related fiascos would never be excessively [1]. These days, the expansion of the limit of modern creation, the interest of human movement and the water contamination, we are confronting more genuine clean water shortage than any time in recent decades. Thus, an assortment of water treatment advances has been created to filter contaminated water so as to accomplish reasonable water use [2,3].

Since, past 20th century, the flourishing explores on different bio-nanomaterials have been changed our experience with numerous major procedures what's more, carried progressive advancements to different building viewpoints. For models, the exposure of carbon based nano biomaterials like, graphene and carbon nanotubes has caught the creative mind of utilizing its shocking optical and electronic properties for different application prospects[4]. The advancement of nanolithography innovation permits the command over the shape, size and piece of structure on the length of 1-100 nm with effective openings in various areas to running different clinical diagnostics. This accomplishment in nanotechnology additionally improves new open doors for water purification strategies. Recent reviews summarized representative examples of how nanotechnology creates novel materials that could enrich some water treatment frameworks with excellent properties, for example adsorptive, synergist, electrical or potentially antimicrobial, that improve cost-efficiency[5-7].

A promising advance forward into the scaled-up utilization of these nanomaterials requires their immobilization inside different substrates to shape composite materials, which are alluded to as nanocomposites in this report. The substrate in the nanocomposites gives not just minuscule space to the convenience of nanoparticles, yet additionally naturally visible shapeable structure and processability. The nanosized spatial limitation gave by the substrate has been named as nanoconfinement. More critically, nanoconfined water shows unusual properties furthermore, practices, for example temperature height of the freezing transition and bizarrely low dielectric constant[8]. Meanwhile, the vehicle of water and particles inside nanoconfined channels doesn't follow the continuum transport model for bulk. As of late, propelled by the new information picked up from the essential investigations on nanoconfinement, researchers have attempted to investigate the use of nanoconfinement in different fields. For heterogeneous catalysis, nanoconfinement with one of kind geometric and electronic structures has been utilized to adequately balance the reactant execution of the restricted dynamic species[9,10]. Despite few existing models indicating the improved toxin expulsion effectiveness under nanoconfine-

*Corresponding author: e-mail driniyasahamed@shctpt.edu,
[1]Department of Biochemistry, Sacred Heart College (Autonomous),
[2]Department of Biochemistry, Sacred Heart College (Autonomous),
Tirupattur, Tamil Nadu, India.

ment, a methodical comprehension on the connection between the extraordinary properties of materials and water atoms under nanoconfinement and the poison expulsion is in pressing need. In this audit, we might want to utilize a new point of view on how nanoconfinement could alter our understandings on different procedures engaged with water treatment[11-13].

Nano-manufacturing offers Versatile Structural designs and Effective Functions of Wood Materials for Water-Dependent Applications

Wood possesses dynamic hierarchical constructions with a number of orders of magnitudes to support several functions which plants promote for effective growth. The cell wall of the plants are initially prepared by the composition of lignin, cellulose and hemicelluloses construct micro fibrils with nanometer scale further the micro fibrils were arranged in the parallel manner to provide structural support to the plant growth and development[14]. The cellulose micro fibrils are basically arranged with the size of 3-10 nm width and 10-30 micrometer long. It can be separately examined and isolated to become nanocellulose crystals/fibers. There nanocellulose would be considered as building blocks with effective functional filaments, membranes, films, aerogels and hydrogels. This existing nanocellulose are possessed and used in the water treatment process. In addition it is used in the form of water filter membrane to increase permeability, increased pressure, adsorption capability and improved elimination of contaminants through interaction of nanoparticles with different modification processes. Compared to the bottom-up nanocellulose emerged with a new top down approach. Vertical dimension channels with the size of around 20-130 micrometers tree trunks were called vessels which took up charge of water and tree crown[15-18].

Several microns were existing on the vessels of the walls which helped to disperse the contaminated water and several ions in the water in radial direction in the trunk. The arranged abundance of pits not only has anisotropic mechanical properties and also the water can transport in multi directions. The naturally existing hierarchical mesoporous wood materials and its structures provide improved separation of materials. Naturally a tree absorbs carbon dioxide and harnesses the energy from the sun to carry out special structural properties[19,20]. Figure 1 demonstrates that functionalized wood based materials offer different water treatment applications. In addition the alternated naturally existing wood materials shows a variety of functions can be offered with prescribed catalytic, adsorptions, desalinations, filtrations and formation of energy. These functionalized nanomaterials which play an important role in bioremediation of water to protect the economy of water[21].

Figure 1. Nanowood developmental, versatile parameters and dynamic function offers various water dependent applications [22].

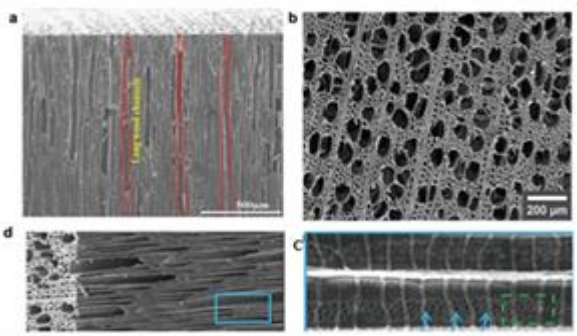

Figure 2. Different characteristic parameters of naturally existing mesoporous wood materials[22].

Table 1 - Different characteristic features of natural and engineered nanowood materials [22]

Natural wood		Engineered nanowood	
Characteristics	Modification	Characteristics	Application
Nonconductive	Carbonization	Electro-conductive	Energy generation, storage, and delivery
Non-catalytic	Particle immobilization	Highly reactive	Contaminant degradation
Low light adsorbing efficiency	Carbonization	Enhanced light adsorbing efficiency	Solar heating and desalination
Hydrophilic	Chemical treatment	Hydrophobic	Oil adsorption and vapor transport
Mesoporous and small pores	Delignification	Increased porosity and pore size	Water and vapor transport

Cellulose mediated membrane filter for water treatment

The chief characteristic of wood is cellulose nanomaterials including cellulose and nanocellulose dependent nanofibers are effectively used as membrane filtration fabrication processes. When compared to all other nanomaterials cellulose mediated nanomaterial and carbon nanotubes are considered eco-friendly, cost effective and renewable material. In the cellulose dependent nanomaterials carry out unique features with increased hydroxyl groups and effective mechanical strength[24]. Cellulose acetate and cellulose derivatives were first mixed in organic solvents and made as desalination membranes in the 1950s and offers reverse osmosis for commercial proceses. Nanosized materials offer great attention to improve the permeability and increased hydrophilicity and smooth surface to decreased membrane fouling. It has strong mechanical property and it can withstand high pressure. Number of studies expressed that cellulose mediated materials offer great attention towards membrane filter processes which were considered emerging innovative strategies in the water economy. It includes nanofiltration, ultrafiltration and forward osmosis were expressed in table 2. Cellulose mediated membrane filters can be formed by using different methods to get desired functional goals. It may include very common blending, vacuum filter, phase inversion and also interfacial polymerization. The eminent scientist fabricated based on cellulose based membrane from wood which offers great attention on bioremediation of water with different parameters[25-29].

Table 2: Summary on cellulose mediated membrane for water treatment [30]

Materials	Process	Feed Solution	Fabrication Process	Rejection	Other	Permeability
Cellulose nanocrystal	Ultra filtration	1000 ppm Na2SO4	Vacuum filtration and interfacial polymerization	97%	Less than 5% rejection of NaCl	34 LMH/bar
Hydrophobic trimethylsilyl cellulose	Ultra filtration	1000 ppm sucrose	Spin coating	80% of sucrose with MWCO of 342	Nearly 0% rejection of NaCl	1.5 LMH/bar
Nanofibrillated cellulose	Ultra filtration	Poly(ethylene glycol)	Spin coating	MWCO between (6 & 26 kDa)	Pure cellulose material	4 LMH/MPa
Hydrophilic cellulose nanocrystal	Ultra filtration	Bovine serum albumin (BSA) solution	Blending-phase inversion	40% of BSA (MWCO - 68000)	Fouling resistance decreased by 48.8%	21 LMH/MPa
Ag- and Pt-decorated nanocellulose	Flow operation	5% w/v NaCl draw solution	Nonsolvent induced phase separation	1.2–1.4 gMH (reverse salt flux)	Electrochemical and antimicrobial reactive	10.24 LMH/bar
Cellulose nanocrystal	Ultra filtration	DI water	Blending and phase inversion	-	High tensile strength of 2.6 MPa	7048 LMH/MPa

The movement of water in the membrane was used as irreversible fouling resistance which was decreased by 48.8 % that treated with modified modelfoulant BSA were represented in the figure 3 a and b. The elimination or removal of nano membranes towards BSA decreased in the ranges around 90 to 40 percent. The different characteristic study was determined and expressed in the figure 3 a - f. The improved physical and mechanical strength of the obtained membrane were stable removal of monovalent ions like NaCl. The activity of the membrane was observed in increased level when compared with commercially available membranes. In addition, the elimination of NaCl was achieved by using commercially existing membranes like NF and it shows great attention and approximately zero NaCl elimination with the molecular weight of 300 Da. In the membrane filtration process nanocellulose offers enhanced performance of FO membrane filters [31,32]. The increased aspects of nanocellulose biomaterials allowed improved density entrapped and FO membrane synthesized with Pt and Ag nanoparticles entrapped nanocellulose as additional sources. The NF and FO membrane shows great antimicrobial activity and electrochemically reactive. Desalination of these fabricated membranes poses around 60% of increased water influx and out flux in commercially available membranes[33].

Catalytic Contaminant Elimination of Mesoporous Bulk Wood Structures

The properties of the cellulose mediated membrane filter shows great intensive application on waste water treatment. The narrow utilization of modified wood based materials offers great attention in number of fields. The extended channels shows huge impact in the bioremediation process ofwater and translocation of different ions by the interaction between the wood surface area and water. The increased surface area of the wood

possess huge number of hydroxyl groups in the cellulose acts as active sites for catalyst immobilization and catalyst[38]. When the wood is allowed to interact with targeted nanoparticles shows great impact in the bioremediation process of contaminated water was performed in situ degradation of contaminants in the water were expressed in table 3. The summery expressed how the different nanomaterial mediated and fabricated wood materials shows improved micro reactors for the elimination of wastes in the water. The existing challenges and advantages offers either oxidation or reduction process [39].

Initially the emergence of nanoparticles (Pd NPs) wood based water purification was achieved by performing methylene blue as a contaminated sample. The obtained wood pieces were socked and heated into the Pd NPs solution for 12 hours at 80˚ C. for unique deposition or interaction of nanoparticles to the wood sample. From this the Pd ion reduction was achieved by lignin and more stable immobilization by hydroxyl groups. Then, the prepared methylene blue sample was passed into the fabricated wood material. By this action Pd activates H_2 which acts as an effective reducing agent for contaminant reduction. NaBH4 was allowed to interact with water and effectively collected H_2 [40].

From the obtained sample it was confirmed that the bioremediation was achieved around 99.8 % with the initial concentration of 30 ppm was eliminated and a maximum or increased flux ratio of 10^5 LMH which was represented in the figure 4 c & d. The conversion of reactant by the wood material was achieved around 2 molar of methylene blue mol Pd^{-1} min^{-1}. In addition silver nanoparticles were incorporated with wood membrane shows great at tention bioremediation of contaminated water and also it shows improved activity towards filter the microorganisms like *E.coli* and *S.aureus* which was represented in figure 4 e -g. from these investigation revealed that, the bioremediation of contaminated water is still in emerging condition and it requires more attention to the investigators to eliminate the contaminants in the drinking water [41-44].

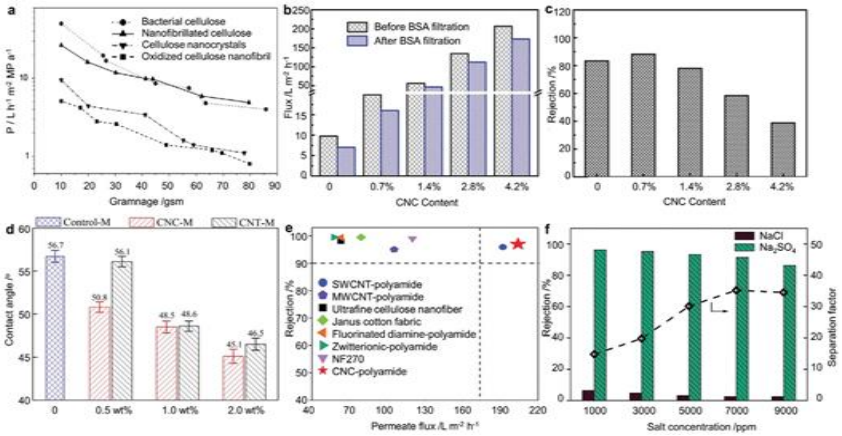

Figure 3: a) Movement of water in cellulose membrane, b,c) BSA filtration at different CNC in before and after membrane fluxes and rejections, d) CNC and CNT entrapped ultrafiltration membrane, e) NF and CNC interacted membrane, f) Na_2SO_4 and NaCl removal at different salt concentration[34-37].

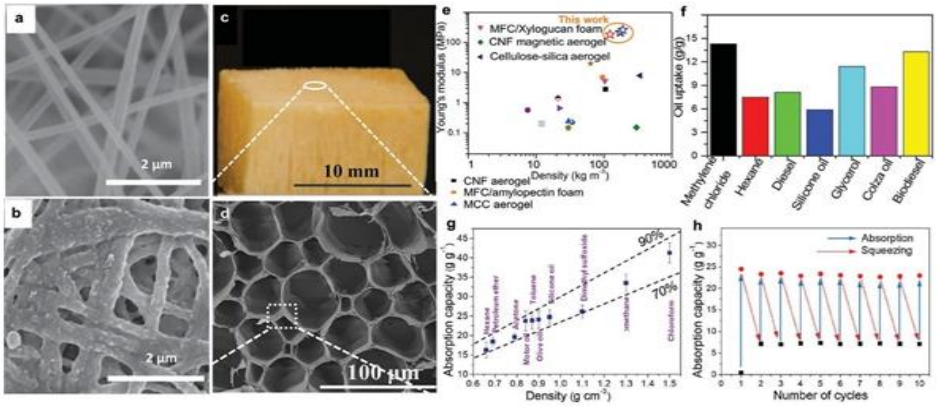

Figure 4: Elimination of contaminants by nanowood materials a) mesoporous figure of naturally existing wood, b) Bioremediation of MB by Pd NPs incorporated wood material, c) property of MB elimination, d) permeate fluxes, e) OD for different bacterial consortium with different time,f,g) Mn_3O_4/ TiO_2 decorated wood under several magnification (SEM), h-j) Mn, Ti and O mapping[45] .

Table 3: Different characteristic property of catalytic or adsorptive nanowood reactors and materials for reduction of pollutants [22]

Process	Contaminant	Modified Material	Removal mechanism	Performance
Batch reactor	30 ppm methylene blue (MB)	Carbonized basswoo+ Fe-Mn–O nanosheet	Chemical reduction with $NaBH_4$	Up to 99.8% removal
Flow-through reactor	10 ppm Methylene blue *E. coli* and *S. aureus*	Radiate pine sapwood (softwood)+ Ag NPs	Chemical reduction with $NaBH_4$	Up to 98.5% MB elimination 5.2–6 orders pathogen elimination
low-through reactor	10 ppm MB	Carbonized first wood + TiO_2 and Mn O NPs	Chemical oxidation with H_2O_2	Up to 95% removal
Flow-through reactor	30 ppm methylene blue (MB)	Basswood + Pd NPs	Chemical reduction with $NaBH_4$	Up to 99.8% elimination

Chemical adsorption for functionalized and cellulosic composite in bulk wood material

Total wood segments and cellulosic composites show improved mechanical strength and good porous structure and increased surface area. These properties shows unique for chemical and physical adsorption of different pollutants like dyes, hydrocarbons, heavy metals and other mixed organic compounds. The existing of hydroxyl group-in the wood material offers increased adsorption capability to the desired contaminants. From the figure 5 the celulosic fiber mediated nanofiber adsorption studies on heavy metals in after and before interaction [46].

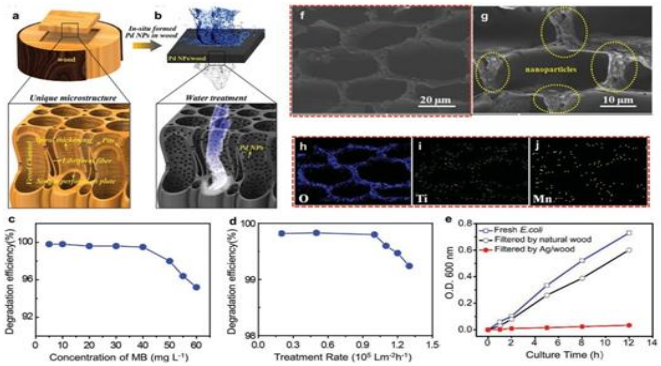

Figure 5: Characteristic image of cellulosic nanofiber mediated filter for adsorption of heavy metals by before and after interaction [47].

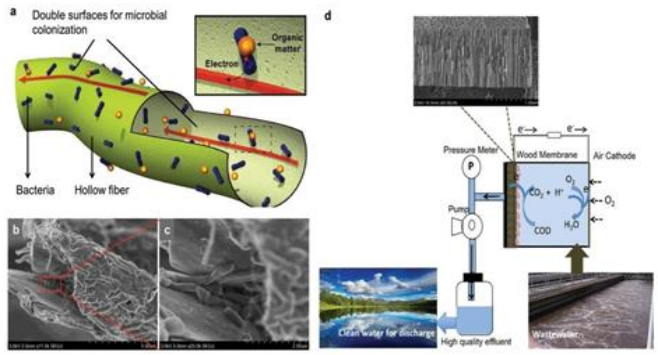

Figure 6: Different electo-conductive and electro active bacterial adsorption studies[50]

The emerging investigations make a key note to the bioremediation of heavy metals, oil traces and other toxic contaminants. Those obtained and prepared natural or fabricated wood materials shows improved tensile strength of 5.19MPa and increased binding ability to Cd like heavy metals around 25-10 mg g^{-1}. Modification of hydroxyl group in the cellulosic membrane modifies the adsorption capacity of the heavy metals. As determined above effective wood materials shows preliminarily investigated for oil, heavy metals and other toxic contaminants adsorption studies. In addition simple modified chemicals have been investigated and the obtained materials may deal different difficulties in the multiple pollutants in tested samples [48]. The efficiency was noted and it was optimized with standard samples in the fabricated and natural samples. The increasing concentration of co-ions like sodium and potassium in water may decrease the binding efficiency of heavy metals in the wood membrane [49]. The different electro active and electro conductive bacterial attractions were shown in the outer surface of the wood materials were observed in the figure 6.

Conclusion

With expanding uneasiness encompassing the exhaustion of common assets and crumbling of the earth, more consideration has been coordinated to manageable turn of events, so as to safeguard our planet for people in the future. With its huge and inexhaustible crude material flexibly, the woodland can furnish us with materials that can be utilized in about each part of our day by day life to supplant impractical and vitality concentrated man-made materials. Changing to ecologically amicable, inexhaustible, and reasonable wood-based crude materials has pulled in enormous intrigue, and critical advancement has been constructed as wood depended progressive confinements. In view of beginning nanomaterials, two dynamic inverse plan methodologies has been evaluated and summed up here.

From this review, it gives an outline of different minimal effort adsorbents instead of costly business adsorbents utilized for the viable expulsion of fluoride from water. The effectiveness of various adsorbents is relying upon

boundaries, for example, pH, adsorbent portion, surface territory, contact time, temperature and introductory fluoride fixation. The expulsion limit increments by expanding portion of the adsorbent and diminishing size of the adsorbent. The WHO norms endorse 1.5 ppm as most extreme level of fluoride in drinking water. The future examination ought to be focused on improvement of powerful and financial defluoridation adsorbents with legitimate local or network units for creating nations as far as cost and practicality for the evacuation of fluoride.

Acknowledgment

Authors thank the Secretary and Principal of Sacred Heart College (Autonomous), Tirupattur for having provided the necessary facilities.

References

[1] Niyas Ahamed M. I, Ragul V, Anand S, Kaviyarasu K, Chandru V and Prabhavathi B, "Green synthesis and toxicity assessment of nanozerovalent iron against chromium contaminated surface water", International Journal of Nanoparticles 2018, 10, 4, 312-325,

[2] Niyas Ahamed M. I, Sathya S, Ragul. V, An *in vitro* study on Hexavalent Chromium [Cr(VI)] Remediation using Iron Oxide Nanoparticles Based Beads, Environmental Nanotechnology, Monitoring & Management 2020,14, 1-5.

[3] Vidiella del Blanco, M.; Fischer, E. J.; Cabane, E. Underwater superoleophobic wood cross sections for efficient oil/water separation. Adv. Mater. Interfaces 2017, 4 (21), 1700584.

[4] Boutilier, M. S. H.; Lee, J.; Chambers, V.; Venkatesh, V.; Karnik, R. PLoS One 2014, 9 (2), e89934.

[5] Chen, F.; Gong, A.; Zhu, M.; Chen, G.; Lacey, S. D.; Feng, J.; Li, Y.; Wang, Y.; Dai, J.; Yao, Y.; Song, J.; Liu, B.; Fu, K.; Das, S.; Hu, L. Mesoporous, three-dimensional wood membrane decorated with nanoparticles for highly efficient water treatment. ACS Nano 2017, 11 (4), 4275−4282.

[6] Hai, J.; Chen, F.; Su, J.; Fu, X.; Wang, B. Porous wood members-based amplified colorimetric sensor for Hg2+ detection through Hg2+-triggered methylene blue reduction reactions. Anal. Chem. 2018, 90 (7), 4909−4915.

[7] Rehan, M.; Mashaly, H. M.; Mowafi, S.; El-Kheir, A. A.; Emam, H. E. Multi-functional textile design using in-situ Ag NPs incorporation into natural fabric matrix. Dyes Pigm. 2015, 118, 9−17.

[8] Heydarifard, S.; Pan, Y.; Xiao, H.; Shipin, O. Water-resistant cellulosic filter containing non-leaching antimicrobial starch for water purification and disinfection. Carbohydr. Polym. 2017, 163, 146−152.

[9] Qian, L.; Xiao, H.; Zhao, G.; He, B. Synthesis of modified guanidine-based polymers and their antimicrobial activities revealed by AFM and CLSM. ACS Appl. Mater. Interfaces 2011, 3 (6), 1895− 1901.

[10] Radetić, M. Functionalization of textile materials with silver nanoparticles. J. Mater. Sci. 2013, 48 (1), 95−107.

[11] Su, C.; Liu, L.; Zhang, M.; Zhang, Y.; Shao, C. Fabrication of Ag/TiO2 nanoheterostructures with visible light photocatalytic function via a solvothermal approach. CrystEngComm 2012, 14(11), 3989−3999.

[12] Maneerung, Cabrales, L.; Abidi, N.; Manciu, F. Characterization of developing cotton fibers by confocal raman microscopy. Fibers 2014, 2 (4), 285−294.

[13] Mthombeni, N. H.; Mpenyanamonyatsi, L.; Onyango, M. S.; Momba, M. N. Breakthrough analysis for water disinfection using silver nanoparticles coated resin beads in fixed-bed column. J. Hazard. Mater. 2012, 217, 133−140.

[14] Sawada, I.; Fachrul, R.; Ito, T.; Ohmukai, Y.; Maruyama, T. Matsuyama, Development of a hydrophilic polymer membrane containing silver nanoparticles with both organic antifouling and antibacterial properties. H. J. Membr. Sci. 2012, 387, 1−6.

[15] World Health Organization. Guidelines for Drinking-water Quality: Fourth ed.; World Health Organization: Geneva, 2011.

[16] Le Ouay, B.; Stellacci, F. Antibacterial activity of silver nanoparticles: A surface science insight. Nano Today 2015, 10 (3), 339−354.

[17] Xue, C.; Chen, J.; Yin, W.; Jia, S.; Ma, J. Superhydrophobic conductive textiles with antibacterial property by coating fibers with silver nanoparticles. Appl. Surf. Sci. 2012, 258 (7), 2468−2472.

[18] Jiang, F.; Li, T.; Li, Y.; Zhang, Y.; Gong, A.; Dai, J.; Hitz, E.; Luo, W.; Hu, L. Wood-based nanotechnologies toward sustainability. Adv. Mater. 2018, 30 (1), 1703453.

[19] Zhu, H.; Luo, W.; Ciesielski, P. N.; Fang, Z.; Zhu, J. Y.; Henriksson, G.; Himmel, M. E.; Hu, L. Wood derived materials for green electronics, biological devices, and energy applications. Chem. Rev. 2016, 116 (16), 9305−9374.

[20] Mecha, C. A.; Pillay, V. L. Development and evaluation of woven fabric microfiltration membranes impregnated with silver nanoparticles for potable water treatment. J. Membr. Sci. 2014, 458, 149−156.

[21] Rayner, J.; Zhang, H.; Schubert, J.; Lennon, P.; Lantagne, D.; Oyanedel-Craver, V. Laboratory investigation into the effect of silver application on the bacterial removal efficacy of filter material for use on locally produced ceramic water filters for household drinking water treatment. ACS Sustainable Chem. Eng. 2013, 1 (7), 737−745.

[22] Soroush, A.; Ma, W.; Silvino, Y.; Rahaman, M. S. Surface modification of thin film composite forward osmosis membrane by silver-decorated graphene-oxide nanosheets. Environ. Sci.: Nano 2015, 2 (4), 395−405.

[23] Dankovich, T. A. Microwave-assisted incorporation of silver nanoparticles in paper for point-of-use

water purification. Environ. Sci.: Nano 2014, 1 (4), 367–378.

[24] Huang, L.; Zhao, S.; Wang, Z.; Wu, J.; Wang, J.; Wang, S. In situ immobilization of silver nanoparticles for improving permeability, antifouling and antibacterial properties of ultrafiltration membrane. J. Membr. Sci. 2016, 499, 269–281.

[25] Loo, S. L.; Fane, A. G.; Krantz, W. B.; Lim, T. T. Emergency water supply: A review of potential technologies and selection criteria. Water Res. 2012, 46 (10), 3125–3151.

[26] Westerhoff, P.; Alvarez, P.; Li, Q.; Gardea-Torresdey, J.; Zimmerman, J. Overcoming implementation barriers for nanotechnology in drinking water treatment. Environ. Sci.: Nano 2016, 3(6), 1241–1253.

[27] Mohammed, N.; Grishkewich, N.; Tam, K. C. Cellulose nanomaterials: promising sustainable nanomaterials for application in water/wastewater treatment processes. Environ. Sci.: Nano 2018, 5(3), 623–658.

[28] Park, C. M.; Chu, K. H.; Heo, J.; Her, N.; Jang, M.; Son, A.; Yoon, Y. Environmental behavior of engineered nanomaterials in porous media: a review. J. Hazard. Mater. 2016, 309, 133–150.

[29] Zeng, X.; Wang, G.; Liu, Y.; Zhang, X. Graphene-based antimicrobial nanomaterials: rational design and applications for water disinfection and microbial control. Environ. Sci.: Nano 2017, 4 (12), 2248–2266.

[30] He, Z.; Xu, S.; Shen, W.; Wang, M.; Li, C. Exploring external and internal pressures on the environmental behavior of paper enterprises in China: A qualitative study. Bus. Strategy Environ. 2019, 28, 951–969.

[31] Jin, Q.; Li, Y.; Yang, D.; Cui, J. Chitosan-derived threedimensional porous carbon for fast removal of methylene blue from wastewater. RSC Adv. 2018, 8, 1255–1264.

[32] Thebo, K. H.; Qian, X.; Zhang, Q.; Chen, L.; Cheng, H.-M.; Ren, W. Highly stable graphene-oxide-based membranes with superior permeability. Nat. Commun. 2018, 9, No. 1486.

[33] Ioannou-Ttofa, L.; Foteinis, S.; Chatzisymeon, E.; Fatta- Kassinos, D. The environmental footprint of a membrane bioreactor treatment process through life cycle analysis. Sci. Total Environ. 2016, 568, 306–318.

[34] Xu, S.-C.; Gao, C.; Miao, Y.-M.; Shen, W.-X.; Long, R.-Y.; Chen, H.; Zhao, B.; Wang, S.-X. Calculation and decomposition of China's embodied air pollutants in Sino-US trade. J. Cleaner Prod. 2019, 209, 978–994.

[35] Almaamary, E. A. S.; Abdullah, S. R. S.; Hasan, H.; Rahim, R. A. A.; Idris, M. Treatment of methylene blue in wastewater using Scirpus grossus. Malays. J. Anal. Sci. 2017, 21, 182–187.

[36] Li, S.; Li, H.; Liu, J.; Zhang, H.; Yang, Y.; Yang, Z.; Wang, L.; Wang, B. Highly efficient degradation of organic dyes by palladium nanoparticles decorated on 2D magnetic reduced graphene oxide nanosheets. Dalton Trans. 2015, 44, 9193–9199.

[37] Zeb, M. H.; Shabbir, B.; Sagar, R. U. R.; Mahmood, N.; Chen, K.; Qasim, I.; Malik, M. I.; Yu, W.; Hossain, M. M.; Dai, Z.; et al. Superior Magnetoresistance Performance of Hybrid Graphene Foam/ Metal Sulfide Nanocrystal Devices. ACS Appl. Mater. Interfaces 2019, 11, 19397–19403.

[38] Fu, Q.; Ansari, F.; Zhou, Q.; Berglund, L. A. Wood nanotechnology for strong, mesoporous, and hydrophobic biocomposites for selective separation of oil/water mixtures. ACS Nano 2018, 12, 2222–2230.

[39] Gu, Z.; Shi, X.; Omari-Siaw, E.; Zhu, Y.; Li, H.; Guo, M.; Yang, X.; Yu, J.; Xu, X. Self-microemulsifying sustained-release pellet of Ginkgo biloba extract: Preparation, in vitro drug release and pharmacokinetics study in beagle dogs. J. Drug Delivery Sci. Technol. 2017, 37, 184–193.

[40] Sagar, R. U. R.; Galluzzi, M.; Wan, C.; Shehzad, K.; Navale, S. T.; Anwar, T.; Mane, R. S.; Piao, H.-G.; Ali, A.; Stadler, F. J. Large, linear, and tunable positive magnetoresistance of mechanically stable graphene foam–toward high-performance magnetic field sensors. ACS Appl. Mater. Interfaces 2017, 9, 1891–1898.

[41] Chen, F.; Gong, A. S.; Zhu, M.; Chen, G.; Lacey, S. D.; Jiang, F.; Li, Y.; Wang, Y.; Dai, J.; Yao, Y.; et al. Mesoporous, threedimensional wood membrane decorated with nanoparticles for highly efficient water treatment. ACS Nano 2017, 11, 4275–4282.

[42] Zhou, L.; Zhuang, S.; He, C.; Tan, Y.; Wang, Z.; Zhu, J. Selfassembled spectrum selective plasmonic absorbers with tunable bandwidth for solar energy conversion. Nano Energy 2017, 32, 195–200.

[43] Rehman Sagar, R. U.; Shehzad, K.; Ali, A.; Stadler, F. J.; Khan, Q.; Zhao, J.; Wang, X.; Zhang, M. Defect-induced, temperatureindependent, tunable magnetoresistance of partially fluorinated graphene foam. Carbon 2019, 143, 179–188.

[44] Chong, W. C.; Chung, Y. T.; Teow, Y. H.; Zain, M. M.; Mahmoudi, E.; Mohammad, A. W. Environmental impact of nanomaterials in composite membranes: Life cycle assessment of algal membrane photoreactor using polyvinylidene fluoride–composite membrane. J. Cleaner Prod. 2018, 202, 591–600.

[45] Abdelhafez, A.A., Li, J., 2016. Removal of Pb(II) from aqueous solution by using biochars derived from sugar cane bagasse and orange peel. J. Taiwan. Inst. Chem. Eng. 61, 367-375.

[46] Abdolali, A., Ngo, H.H., Guo, W., Lu, S., Chen, S.S., Nguyen, N.C., Zhang, X., Wang, J., Wu, Y., 2016. A breakthrough biosorbent in removing heavy metals: equilibrium, kinetic, thermodynamic and mechanism analyses in a lab-scale study. Sci. Total Environ. 542, 603-611.

[47] Ahmad, A., Ghazi, Z.A., Saeed, M., Ilyas, M., Ahmad, R., Khattaka, A.M., Iqbal, A., 2017. A comparative study of the removal of Cr(VI) from synthetic solu-

tion using natural biosorbents. New J. Chem. 41, 10799-10807.

[48] Arora G, Bhateja S. 2014. Estimating the fluoride concentration in soil and crops grown over it in and around Mathura, Uttar Pradesh, India. Am J Ethno Med 1(1):36–41

[49] He, Y. An, and F. Zhang,. 2013. "Geochemical characteristics and fluoride distribution in the groundwater of the Zhangye Basin in Northwestern China," Journal of Geochemical Exploration,.135,. 22–30.

[50] Mohammed, H. Gomma, D. Ragab, and J. Zhu,. 2016. "Magnetic nanoparticles for environmental and biomedical applications: Review," Particuology, 30, 1.

[51] Barathi, A. S. K. Kumar, and N. Rajesh,. 2019. "Impact of fluoride in potable water - an outlook on the existing defluoridation strategies and the road ahead," Coordination Chemistry Reviews, vol. 387, pp. 121–128.

[52] Chen, M,; Zhu, L.; Dong, Y.; Li, L.; Liu, J. (2016). Waste-to-Resource Strategy To Fabricate Highly Porous Whisker-Structured Mullite Ceramic Membrane for Simulated Oil-in-Water Emulsion Wastewater Treatment. *ACS Sustainable Chemistry* & *Engineering.* 4, 2098-2106.