Bulgarian Chemical Communications, Volume 54, Special Issue C (pp.78-83) 2022 *DOI: 10.34049/bcc.54.C.0078*

Wastewater treatment by emerging wastewater treatment technologies: A systematic review

Rukshar, N. Bhatnagar*

Department of Chemistry, Manipal University Jaipur, Jaipur-Ajmer Expressway, Jaipur, Rajasthan, 303007, India

Accepted: July 06, 2022

Environmental chemists, engineers, and water authorities face a significant difficulty in the treatment of industrial effluent. Non-biodegradable materials are commonly utilized in various industries such as textile dyeing and printing processes. Many pollutants and toxins are introduced into water bodies by agriculture and industry. This not only has an impact on water quality, but it also puts various aquatic species in jeopardy. Although considerable progress has been made in the treatment and management of such wastewater using chemical or biological processes, there is a developing shift in the approach, with the focus turning to resource recovery and sustainable wastewater management. By wastewater treatment process, solids in polluted water are partially extracted and converted by decomposition method into simple molecules or minerals. Primary and secondary treatment processes remove the bulk of BOD and total suspended solids found in polluted water. However, this treatment method is increasingly becoming unsuitable to safeguard receiving waterways or offer useable water for commercial and domestic recycling. Advanced treatment procedures rank quite high in terms of giving a true answer for destroying stuff that is resistant to traditional treatment. In this article, we have made a conscientious attempt to review advanced remediation techniques.

Keywords: Environment; Oxidation; Pollutants; Wastewater

INTRODUCTION

Waste effluents have always been recognized as a source of health and environmental hazards. Sometimes complicated compositions of waste fluids necessitate complex treatment techniques with correspondingly high prices, which are impracticable given the vast amounts of waste generated by both home and industrial use [1]. Therefore, it is required to develop low-cost and simple decontamination techniques for the treatment of waste water. Today various technologies like nanomembrane, advance oxidation process, nanopowder and biodegradation are used for isolation and elimination of biochemical substances which include various metals (e.g. Cd, Pb, Cu, Hg, Zn, Ni), nutrients (e.g. PO^{3-}, NH, NO^{-}, NO^{-}), CN^{-}, organic compounds, microorganisms (e.g. cyano-bacteria) viruses, antibiotics, bacteria and parasites [2]. The contamination of fresh water sources occurred by expanding population, urbanization, global climate warming, industrialization, and deficiency of efficient management practices of water resources [3]. Cholera, malaria, and diarrhea are caused by a lack of safe drinking water and sanitation in cities [4]. The first municipal water treatment plant was developed in Scotland in the 1800s, and since then, the method has been established for the treatment of municipal and other sewage all over the world [5]. The accumulation of dyes, insecticides, personal care products, phenols, and other organic pollutants in water has turned out to be a main cause of water pollution [6-9]. These pollutants have a negative impact on aquatic life, as well as human health. Conventional wastewater treatment systems have a hard time removing these organic contaminants [10]. Their decomposition is primarily accomplished through acidic putrefaction, heating of wastewater, or biological treatment techniques. The method is based on the biological breakdown of organic materials and contaminants, which is driven by bacterial consortia, in addition to any previous physical and mechanical treatment operations [11]. In recent years, there has been a surge in interest in using various emerging technologies for the treatment of wastewater.

ADVANCED WASTE WATER TREATMENT PROCESSES

Ceramic membrane filtration method:

Ceramic membranes have recently attracted a lot of attention due to their outstanding properties, such as a long operating cycle, easy cleaning, restoration, chemical dependability, and pollution-free treatment of wastewater [12]. Membrane technology is already being used for a range of purposes, and it is becoming more cost-effective as a result of advances in membrane research. Membranes are classified into four categories on the basis of pore size: microfiltration, ultrafiltration, nano-filtration, and reverse osmosis [13-15]. The other three membranes

---

To whom all correspondence should be sent:
E-mail: nitu.bhatnagar@jaipur.manipal.edu

with the exception of RO, are used in industrial wastewater treatment applications.

Ceramic membrane technology is increasingly being used in the treatment of industrial discarded water [16]. Ceramic membrane treatment is appealing due to inherent characteristics such as thermochemical stability, low fouling tendency, and durability, and the ceramic membrane technology market is expected to develop at a compound yearly with a growth rate of 12%. Advanced processes of oxidation, like *in-situ* ozonation, could be incorporated with ceramic membrane, which is not possible with polymeric membranes due to potential breakdown over long-term exposure [17]. Due to higher fluctuation, higher toxin removal, reduced fouling rate, and advanced spring-cleaning efficiency, hybrid-ceramic membrane systems like the ceramic membrane bioreactor outperform polymeric alternatives. Polymer-based membranes currently take over the polluted water treatment sector, and were actively explored for municipal and polluted water treatment since the 1990s. Diverse elements of polymer-based membranes have been studied, reported on, and reviewed, including fabrication methods, full-scale applications, fouling, and prevention [18].

Oxidation

Oxidation is one of the most effective treatment methods. This process produces hydroxyl free radical (OH), a highly reactive and unselective oxidant which has the capacity of abolishing even highly resistant pollutants [19]. Ozone (O_3), H_2O_2, TiO_2, heterogeneous catalyst-based photolysis, radiation, or strong electron ray radiation greatly speed up the generation of hydroxyl free radical [20].

Hydrogen peroxide/UV, hydrogen peroxide/Fe^{++}, H_2O_2/UV/Fe^{++}, O_3/UV are some of the oxidants which are used in this process [21-23]. A titanium peroxide semiconductor traps UV light and creates hydroxyl radicals in the TiO_2/UV light method [24]. Organic compounds can be degraded oxidatively by reacting with valence bond holes, hydroxyl and peroxide radicals, or reductively by reacting with electrons [25]. The ability to operate at divergent temperatures, the need of mass transfer limits when NPs are used for the treatment of polluted water as photo catalysts, and the use of solar irradiation are all advantages of this method [26]. Furthermore, TiO_2 is a low-cost, readily available substance with highly oxidizing photo generated pores. TiO_2 can oxidize a broad range of organic pollutants to produce nontoxic components like CO_2 and H_2O [27]. Injection of hydrogen peroxide and subsequent mixing occur in a reactor equipped with ultra-violet light in the hydrogen peroxide/UV light process (200 to 280 nm) [28]. Ultraviolet light is utilized to break the O-O link in H_2O_2 and form the hydroxyl free radical during this process. Phenolic compounds, malachite green and reactive blue 19 have all been decolorized and degraded by using the UV/H_2O_2 technique. The Fenton process produces $OH^{\cdot}$ by combining ferrous iron (Fe (II)) and H_2O_2 under acidic conditions [29, 30]. The Fenton process has several advantages, including minimal operating costs and the ability to easily magnetically separate residual iron. In this method, a large number of OH free radicals with a powerful oxidizing potential (2.8 V) are formed, which have a short life but are very reactive and target dyes and other pollutants by either extracting a H atom or attaching themselves to multiple bonds. Enhanced ferrous sulfate concentration improves dye removal capacity [31].

Bioremediation

Bioremediation is the most convenient way for emerging organic micro pollutants in wastewater to be removed, and it's a promising way to totally remove these compounds during the treatment of wastewater [32]. Organic contaminants such as aromatic hydrocarbon compounds, phenols, nitro-aromatics compounds, and azo dyes are abundant in salty wastewater generated by the agro-food, petrochemical, textile, and leather manufacturing sectors. Because of the capacity to breakdown hazardous compounds efficiently under high salt conditions, microorganisms such as algae, bacteria are gaining popularity in industrial waste treatment. In co-metabolism techniques, degrading microorganisms use one molecule as a carbon source and another as an energy source, and may be used to biodegrade emerging organic pollutants [33-35].

Nowadays, dye treatment focuses on microorganisms that may break and absorb dyes in wastewater. A variety of microorganisms, including yeast, actinomycetes, fungi, bacteria and algae, have been identified which have dye decolorizing abilities [37]. Microorganism-based detection and removal of heavy metals has a number of distinct benefits, comprising ease of application, low cost, high capacity of adsorption, and widespread availability [38]. Plant-based treatment makes use of a plant's natural biological functions to benefit humans. Water plants are important in biological treatment of wastewater because they may be utilized for phytoremediation technologies such as rhizo-filtration method, phyto-extraction method, phyto-stabilization method, phyto-degradation method, and phyto-transformation method [39].

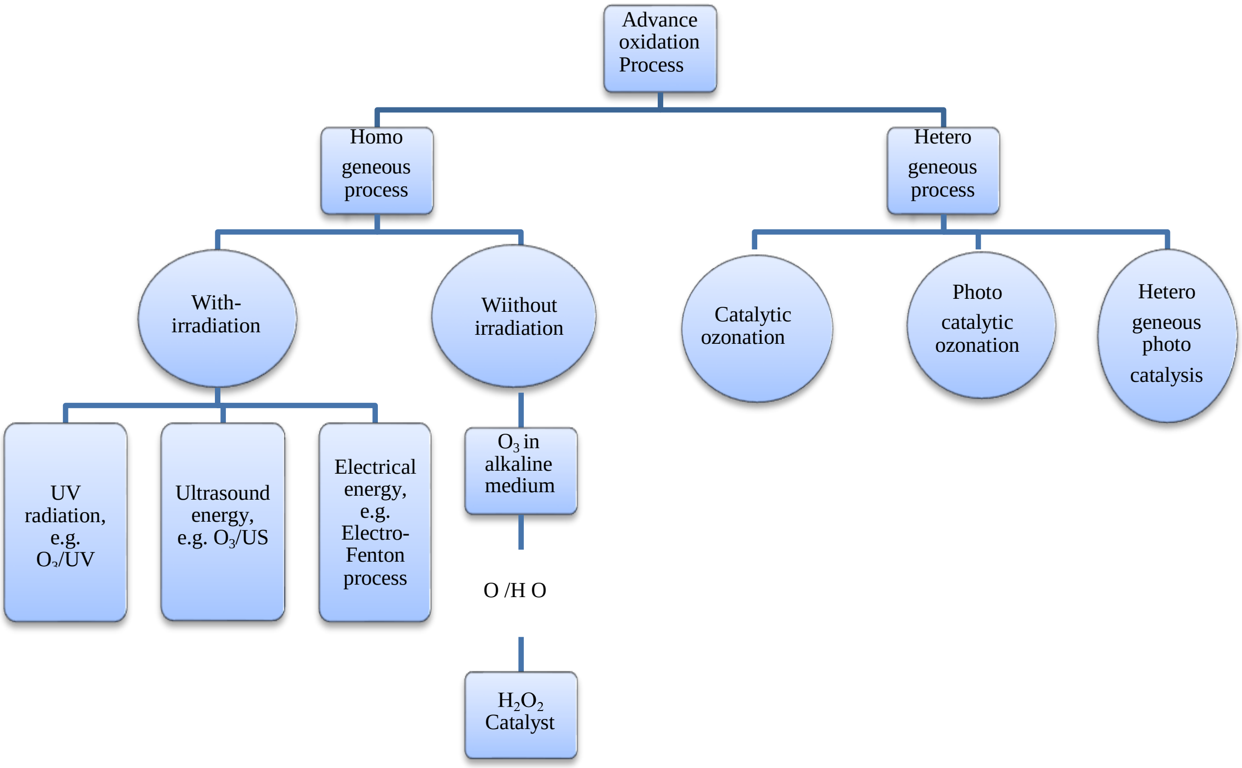

Fig. 1. Classification of advance oxidation processes.

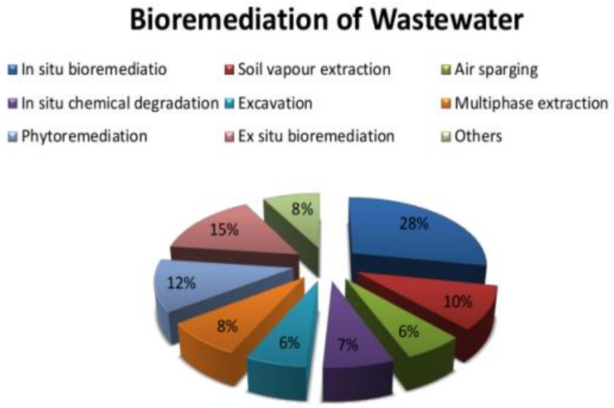

Fig. 2. Various bioremediation methods for the treatment of waste water [36].

Nano particle based treatment

In the twenty-first century, the world's most pressing concern is managing water demand, which is a result of global progress and weather variability. This necessitates current understanding and ways to maintain the safety of clean water and its supply for drinking [40]. The application of fresh and unique nanotechnology opens up possibilities for ensuring the purification of water. The basic demand of industries is to provide cost-effective and steady resources to deliver drinking water at a reasonable level [41]. Because the expanding demand is linked to severe varied health recommendations and pollutants, polluted water treatment techniques are ineffective in giving enough clean water [42]. The extremely resourceful way includes the use of developed nano sized particles as active adsorbents for the removal of contamination from wastewater. Fe-MNPs which are very stable and have high efficiency for the removal of organic pollutants are synthesized by a unique oxidative precipitation-pooled iono-thermal synthesis method and degrade the organic pollutants with H_2O_2 [54].

Table 1. Various NPs and their pollutant removal application.

NPs	Nature of contaminants removed	Ref.
Ag NPs on the surface of PDA-functionalized Al- MOF/Fe_3O_4 nanocatalyst	Organic pollutants such as ciprofloxacin (CIP), norfloxacin (NOR) methyl orange (MO)	[43]
Pd NPs@UN nanocatalyst	4-Nitrophenol (4-NP), hexavalent chromium [Cr(VI)], rhodamine B (RhB), congo red (CR), potassium- hexacyanoferrate(III) ($K_3[Fe(CN)_6]$)	[44]
Nano-ZnO	Phenol	[45]
Metal−organic framework-engineered FeS_2/C nanocatalyst	Fluoxetine	[46]
Iron(II) molybdate nanocatalyst coated anode	sugarcane wastewater industry	[47]
Ag-NP	Rhodamine B and Methylene blue, heavy metal removal	[48,49]
γ-Fe_2O_3-NPs	Textile dyes and heavy metals	[50]
TiO_2 NPs	Photocatalytic treatment of tannery wastewater (COD removal, 82.26%; Cr removal, 76.48%)	[51]
	Photo catalytic degradation of organic dyes (malachite green (MG), 94.15%, and eriochrome black T (EBT), 76.13%)	[52]
Potassium zinc hexacyanoferrate nanocubes	Reduction of hexavalent Cr	[53]
Fe NPs		

Pathogenic magnetic NPs have demonstrated greater nontoxic manufacturing potential and higher pollutant removal performance [55, 56]. However, regeneration and reusability are required in nano-technological applications, particularly for nanoparticles, and have a direct impact on treatment costs and sustainable development [57]. Water filtration technique for the removal or reduction of pollutants, such as suspended particles, microorganisms, and other harmful biological and chemical contaminants in water, in order to produce safe and clean water for drinking, pharmaceutical, and biomedical purposes [58, 59]. The nano-filtration (NF) membrane is the most significant innovation in membrane-based technology. Nano-filtration membranes feature a molecular mass cut-off for nonpolar objects in the nano-metric scales [60, 61].

Adsorption

Adsorption is a rapid, economical, and ubiquitous technique of water filtration and recycling among numerous technologies. The rapid increase of research interests in this subject has been fueled by the introduction of low-cost adsorbents [62]. Adsorption experimental techniques are quickly evolving for the discovery and evaluation of cost-effective adsorbents for water purification and recycling. Carbon-based adsorbents have attracted a lot of interest in the field of wastewater treatment chemistry because of the advantages they provide, such as thermal properties, extracting behavior, adsorptive nature, and specificity [63]. Carbon nanotubes (CNTs), graphene, chitosan biopolymer and bio-char are all examples of adsorbents. Chemisorption, electrolysis, solvent evaporation, nano membrane filtration process, adsorption process, and reverse osmosis are some of the most well studied and widely utilized wastewater treatment methods [64]. Adsorption process is the most important of these techniques because of its qualities such as high efficiency, cost effectiveness, ease of handling, and abundance of adsorbents [65]. New findings have emphasized on the utilization of chitosan biopolymer as a bio-sorbent for heavy metal ion removal, with adsorption being found to be a reliable approach [66]. Electrolysis, micro-precipitation, chelation, and electrostatic attraction are some of the interactions that lead to the creation of bonds between chitosan biopolymer and metal ion during bio-sorption [67].

CONCLUSION

One of the most serious environmental issues is the poisoning of water bodies with chemical toxins. Pollution in water bodies causes a great deal of devastation. As a result, wastewater must be treated before being discarded into the water bodies. A significant increase in the literature on polluted water and advanced treatment processes from 2000 to 2021 has been observed, indicating an emerging research interest in this field. From 2005 onwards, the rise in the number of publications has been particularly notable. The primary goal of treating wastewater is to enable urban and industrial effluents to be disposed of without endangering human health or causing unacceptable environmental harm. Raw municipal wastewater, on the other hand, usually requires some treatment before it can be used for various purposes. Any level of treatment can be achieved using advanced treatment process. In some treatment systems, further processing is required to remove pollutants from contaminated water. Advanced techniques and equipment are used in advanced wastewater treatment plants. They are highly costly to operate, and both operational costs and water quality are affected by the efficiency of operation. To preserve the water bodies that collect effluents, wastewater management operations must be carefully managed. Operators at treatment plants are trained and qualified to monitor and measure the discharged sewage, the treatment process, and the finally discarded effluent. The true objective of treating wastewater should be to manage waste in water in an efficient, cost-effective, and environmentally friendly manner. The main future challenges in using AOPs in treating wastewater may include the development of efficient and low-cost materials to enhance adequate treatment, the use of alternative energy sources, the implementation of process integration methods trying to target various pollutants, and the monetization of laboratory-developed processes.

Acknowledgements: *Presented at the International Conference on "Cutting Edge Research in Materials and Sustainable Chemical Technologies" from January 27 to 29, 2022, organized by Department of Chemical Engineering & Department of Chemistry at Manipal University Jaipur, Jaipur, India (Organizing Chairman: Dr. Anand G. Chakinala & Dr. Rahul Srivastava)***.**

REFERENCES

1. G. Crini, E. Lichtfouse, *Environmental Chemistry Letters*, **17** (1), 145 (2019).
2. M. Salgot, M. Folch, *Current Opinion in Environmental Science & Health*, **2**, 64 (2018).
3. M. Salgot, G. Oron, G. L. Cirelli, N. R. Dalezios, A. Díaz, A. N. Angelakis, CRC Press, Boca Raton FL, USA, 2016.
4. A. S. Laura, G. A. W. L. I. K. Bernd, Minimum quality requirements for water reuse in agricultural irrigation and aquifer recharge-Towards a water reuse regulatory instrument at EU level, Réédition, (2017).
5. S. Wacławek, H. V. Lutze, K. Grübel, V. V. T. Padil, M. Černík, D. D. Dionysiou, *Chemical Engineering Journal*, **330**, 44 (2017).
6. I. A. Saleh, N. Zouari, & M. A. Al-Ghouti, *Environmental Technology & Innovation*, **19**, 101026 (2020).
7. S. Karimifard, M. R. A. Moghaddam, *Science of the Total Environment*, **640**, 772 (2018).
8. M. M. Emamjomeh, M. Mousazadeh, N. Mokhtari, H. A. Jamali, M. Makkiabadi, Z. Naghdali,... R. Ghanbari, *Separation Science and Technology*, **55**(17), 3184 (2020).
9. R. Qadri, M. A. Faiq, Freshwater pollution: effects on aquatic life and human health, in: Fresh water pollution dynamics and remediation, Springer, Singapore. 2020, p. 15.
10. C. P. Ahada, S. Suthar, *Environmental Science and Pollution Research*, **25**(25), 25336 (2018).
11. S.S. Kumar, S. Shantkriti, T. Muruganandham, E. Murugesh, N. Rane, S. P. Govindwar, *Ecological Informatics*, **31,** 112 (2016).
12. A. Alengebawy, K. Jin, Y. Ran, J. Peng, X. Zhang, P. Ai, *Chemosphere*, **267**, 129197 (2021).
13. T. R. Al-Husseini, A. H. Ghawi, A. H. Ali, *Journal of Water Process Engineering*, **30**, 100590 (2020).
14. M. R. Bilad, N. I. M. Nawi, D. D. Subramaniam, N. Shamsuddin, A. L. Khan, J. Jaafar, A. B. D. Nandiyanto, *Journal of Water Process Engineering*, **36**, 101264 (2020).
15. X. Chen, X. Chen, Y. Zhao, H. Zhou, X. Xiong, C. Wu, *Science of the Total Environment*, **719**, 137276. (2020).
16. B. I. Harman, H. Koseoglu, N. O. Yigit, E. Sayilgan, M. Beyhan, M. Kitis, *Water Sci. Technol.*, **62**, 547 (2010).
17. N. U. Barambu, M. R. Bilad, M. A. Bustam, K. A. Kurnia, M. H. D. Othman, N. A. H. M. Nordin, *Ain Shams Eng. J.* (2020).
18. W. Zhang, X. Liu, D. Wang, Y. Jin, *Biores. Technol.*, **243**, 1020 (2017).
19. S. O. Ganiyu, C. A. Martínez-Huitle, M. A. Oturan, *Current Opinion in Electrochemistry*, **27**, 100678. (2021).
20. D. Y. An, J. Y. Park, *Desalin. Water Treat.*, **57**,

26595 2016.

21. K. Barbari, R. Delimi, Z. Benredjem, S. Saaidia, A. Djemel, T. Chouchane, N. Oturan, M. A. Oturan, *Chemosphere*, **203**, 1 2018.
22. B. Bethi, S. H. Sonawane, B. A. Bhanvase, S. P. Gumfekar, *Chem. Eng. Process. Process Intensif.* **109**, 178 *2016)
23. E. B. Cavalcanti, S. Garcia-Segura, F. Centellas, E. Brillas, *Water Res*., (2013).
24. M. R. Espino-Estévez, C. Fernández-Rodríguez, O. M. González-Díaz, J. Arana, J. P. Espinós, J. A. Ortega- Méndez, J. M. Dona-Rodríguez, *Chem. Eng. J.,* (2016).
25. F. A. Gagol,̨ M. Makos, P. Khan, J. A. Boczkaj, *Sep. Purif. Technol*. **224**, 1 (2019).
26. W. De Schepper, J. Dries, L. Geuens, J. Robbens, R. Blust, *Water Res.,* **43**, 4037 (2009).
27. O. Gimeno, J.nF. García-Araya, F. J. Beltrán, F. J. Rivas, A. Espejo, *Chem. Eng. J.* **290**, 12 (2016).
28. S. D. Jojoa-Sierra, J. Silva-Agredo, E. Herrera-Calderon, R. A. Torres-Palma, *Sci. Total Environ*., **575**, 1228 (2017).
29. G. M. Gyeong, J. Y. Park, *Desalin. Water Treat*. **54**, 1029 (2015).
30. M. Kermani, F. Mohammadi, B. Kakavandi, A. Esrafili, Z. Rostamifasih, *J. Phys. Chem. Solids*, (2018).
31. P. Thanekar, S. Garg, P. R. Gogate, *Ind. Eng. Chem. Res.*, **59**, 4058 (2020).
32. E. A. Cezare-Gomes, L. del Carmen Mejia-da-Silva, L. S. Perez-Mora, M. C. Matsudo, L. S. Ferreira-Camargo, A. K. Singh, J. C. M. de Carvalho, *Appl. Biochem. Biotechnol*. **188 (3)**, 602. (2019).
33. D. P. Singh, J. S. Khattar, A. Rajput, R. Chaudhary, R. Singh. *PloS one* ,**14** (9), e0221930. (2019).
34. D. Cheng, H. Ngo, W. Guo, S. Chang, D. Nguyen, S. Kumar, *Bioresour. Technol*. **275**, 109 (2019).
35. G. P. Arone Soul Raj, S. Elumalai, T. Sangeetha, D. Roop Singh, *J. Bioremed. Biodeg.* **6(**294), 2 (2015).
36. J. Pandey, A. Chauhan, R. K. Jain, *FEMS Microbiology Reviews*, **33 (2)** , 324 (2009).
37. S. A. Khan, G. K. Sharma, F. A. Malla, A. Kumar, N. Gupta, *J. Clean. Prod*. **211**, 1412 (2019).
38. M. Aray-Andrade, C. Moreira, V. Santander, L. Mendoza, R. Bermúdez, in: European Biomass Conference and Exhibition Proceedings, Lisbon, Portugal, 2019, p. 241.
39. M. M. Mirzaee, M. Zakeri Nia, M. Farasati, *Cleaner Engineering and Technology,* **4**, 100210 (2021).
40. A. B. Abou Hammad, A. M. El Nahwary, B. A. Hemdan, A. L. K. Abia, *Environmental Science and Pollution Research*, **27**(21), 26668 (2020).
41. F. Almomani, R. Bhosale, M. Khraisheh, T. Almomani, *Applied Surface Science***, 506,** 144924 (2020).
42. M. Govarthanan, C. H. Jeon, Y. H. Jeon, J. H. Kwon, H. Bae, W. Kim, *International Journal of Biological Macromolecules***, 162,** 1241 (2020).
43. Y. Wang, L. He, Y. Li, L. Jing, J. Wang, X. Li, *Journal of Alloys and Compounds,* **828**, 154340. (2020).
44. M. Sajjadi, N. Y. Baran, T. Baran, M. Nasrollahzadeh, M. Reza Tahsili, M. Shokouhimehr, *Separation and Purification Technology*, 116383 (2019).
45. Y. Tao, Z. L. Cheng, K. E. Ting, X. J. Yin, *Journal of Catalysts*, **(1–6)** *(*2013).
46. Z. Ye, J. A. Padilla, E. Xuriguera, J. L. L. Beltran, F. Alcaide, E. Brillas, I. Sirés, *Environmental Science & Technology*, (2020).
47. S. Naina Mohamed, N. Thomas, J. Tamilmani, T. Boobalan, M. Matheswaran, P. Kalaichelvi, A. Pugazhendhi, *Fuel,* **277**, 118119 (2020).
48. X. Meng, C. Duan, Y. Zhang, W. Lu, W. Wang, Y. Ni, *Composites Science and Technology,* 108384. (2020).
49. K. O. Shittu, O. Ihebunna, *Adv. Nat. Sci. Nanosci. Nanotechnol..* **8,** 1 (2017).
50. A. Fouda, S. E.-D. Hassan, E. Saied, M. S. Azab, *Journal of Environmental Chemical Engineering*, **9(1)**, 104693 (2021).
51. S. P. Goutam, G. Saxena, V. Singh, A. K. Yadav, R. N. Bharagava, K. B. Thapa, *Chem. Eng. J.,* **336,** 386 (2018).
52. V. Jassal, U. Shanker, B. S. Kaitha, S. Shankarb, *RSC Adv.*, **5(33).** 26141 (2015).
53. C. Mystrioti, T. D. Xanthopoulou, N. Papassiopi, A. Xenidis, *Sci. Total. Environ.,* **539,** 105 (2016).
54. M. Malakootian, M. R. Heidari, *Zeitschrift für Physikalische Chemie,* **235(6)**, 683 (2020).
55. A. H. Sadek, M. S. Asker, S. A. Abdelhamid, *Biologia,* **76(9)**, *2785* (2021).
56. J. You, L. Wang, Y. Zhao, W. Bao, *Journal of Cleaner Production,* **281**, 124668 (2021).
57. P. Punia, M. K. Bharti, S. Chalia, R. Dhar, B. Ravelo, P. Thakur, A. Thakur, *Ceramics International,* (2020).
58. M. Anjum, R. Miandad, M. Waqas, F. Gehany, M. A. Barakat, *Arab. J. Chem*., **12**, 4897 (2019)
59. S. Sharma, A. Bhattacharya, Drinking water contamination and treatment techniques, *Appl. Water Sci.,* **7,** 1043 (2017).
60. A. Boretti, L. Rosa, *Npj Clean Water,* **2,** 1 (2019).
61. D.K. Tiwari, J. Behari, P. Sen, *World Appl. Sci. J.,* **3,** 417 (2008).
62. A. E. Burakov, E. V. Galunin, I. V. Burakova, A. E. Kucherova, S. Agarwal, A. G. Tkachev, V. K. Gupta, *Ecotoxicol. Environ. Saf*., **148**, 702e712 (2018).
63. S. Y. Cheng, P. L. Show, B. F. Lau, J. S. Chang, T. C. Ling, *Trends Biotechnol*., **37**, 1255e1268 (2019).
64. W. S. Chai, J. Y. Cheun, P. S. Kumar, M. Mubashir, Z. Majeed, F. Banat, P. L. Show, *Journal of Cleaner Production,* **296**, 126589 (2021).
65. C. A. Guerrero-Fajardo, L. Giraldo, J. C. Moreno-Pirajan, *Nanomaterials,* **10** (2020).
66. M. Ahmad, M. Yousaf, A. Nasir, I.A. Bhatti, A. Mahmood, X. Fang, X. Jian, K. Kalantar-Zadeh, N. Mahmood, *Environ. Sci. Technol.*, **53,** 2161 (2019).
67. R. Chakraborty, R. Verma, A. Asthana, S. S. Vidya, A. K. Singh, *Int. J. Environ. Anal. Chem.*, **1,** 1, (2019).