Nanotechnology Perceptions
ISSN 1660-6795
www.nano-ntp.com

"Review on Adsorptive Removal of Dyes from Aqueous Solution: Recent Advancements and Future Perspectives" using the Provided References

Sanjay Kumar Choudhary[1], Nityanand Singh Maurya[2*]

[1]*Department of Leather Technology, Muzaffarpur Institute of Technology, India*
[2]*Department of Civil Engineering, National Institute of Technology Patna, India*
Email: nsmaurya@nitp.ac.in

Synthetic colors released into water supplies from different sectors carry serious environmental and health hazards. Removing dye from wastewater has found a cheap and efficient approach in adsorption. Emphasizing new adsorbent materials, adsorption mechanisms, influencing factors, and future directions, this review offers a thorough summary of current developments in adsorptive dye removal. We examine several adsorbents—activated carbon, agricultural wastes, clay minerals, nanomaterials, metal-organic frameworks, and conducting polymers—critically for their dye removal capability. Furthermore covered in the paper are adsorption kinetics, isotherms, thermodynamics, and wasted adsorbent regeneration. We stress newly developing trends like hybrid systems, nanocomposites, and magnetic adsorbents. Lastly, obstacles and prospective areas of study are described to steer next progress of effective and sustainable adsorption technologies for applications in industry-scale dye removal.

1. Introduction

Textiles, paper, plastics, leather, food, cosmetics, and drugs are just a few of the several sectors where synthetic colors find great application [1-3]. Over 100,000 commercially sold dyes are thought to exist with annual production more than 7 × 105 tons [4]. But a lot of dyes are lost during processing and manufacture, which causes dye-containing effluent discharge into water bodies [5]. Aquatic colors—even at low concentrations—can harm the environment and humans due to their brightness, recalcitrance, and toxicity [6,7].

Dyes are chemically and photolytically stable and can undergo wastewater treatment [8]. Coagulation-flocculation, membrane filtration, advanced oxidation, and biodegradation [9,10] are physical, chemical, and biological dye removal methods for wastewater. Adsorption is the most popular dye removal method because it is easy, adaptable, and inexpensive [11,12].

Dye molecules adsorb on solid adsorbent materials. Adsorption efficiency depends on adsorbent parameters (surface area, pore size, functional groups), dye properties (molecular size, structure, charge), and operation circumstances. Dyes have been removed using a wide range of adsorbent materials, from activated carbons to nanomaterials and composites [15, 16].

The purpose of this review is to give a whole picture of current developments in adsorptive dye removal from aqueous solutions. The review covers historical events in the past ten years and offers required context as well. It is to assess the present state-of-the-art and pinpoint interesting research directions to direct next development of effective and sustainable adsorption technologies for industrial-scale dye removal applications.

2. Dyes: Classification, Properties, and Environmental Impacts

2.1 Classification of Dyes

One can classify dyes depending on their chemical structure, source, or application technique. [8,17]. Some major classes include:

- Azo dyes: Contain one or more azo bonds (-N=N-). Examples: Methyl orange, Congo red
- Anthraquinone dyes: Based on anthraquinone structure. Examples: Alizarin, Acid blue 25
- Triarylmethane dyes: Contain three aryl groups. Examples: Methylene blue, Crystal violet
- Phthalocyanine dyes: Contain phthalocyanine ring. Examples: Copper phthalocyanine
- Indigoid dyes: Contain indigo structure. Example: Indigo carmine
- Sulfur dyes: Contain sulfur in the chromophore. Example: Sulfur black 1[18].

2.2 Properties of Dyes

The key properties of dyes that influence their behavior in aqueous systems and adsorption characteristics include:

- Molecular structure and size
- Solubility
- Ionic nature (anionic, cationic, non-ionic)
- Light fastness
- Chemical and thermal stability

Table 1 summarizes the properties of some common dyes used in adsorption studies.

Table 1: Properties of common synthetic dyes

Dye	Chemical class	Molecular weight	λmax (nm)	Ionic nature
Methylene blue	Thiazine	319.85	664	Cationic
Congo red	Azo	696.66	498	Anionic
Methyl orange	Azo	327.33	464	Anionic
Rhodamine B	Xanthene	479.01	554	Cationic
Acid blue 25	Anthraquinone	416.38	600	Anionic

2.3 Environmental Impacts

The discharge of dye-containing effluents into water bodies can cause serious environmental and health impacts [19,20]:

- Reduced light penetration affecting photosynthetic activity
- Depletion of dissolved oxygen
- Toxicity to aquatic organisms
- Bioaccumulation in the food chain
- Carcinogenic and mutagenic effects on humans
- Aesthetic issues due to visible coloration of water

Many dyes have complex aromatic compounds that make them resistant to light, heat, and oxidizing chemicals, which presents difficulties for their removal and breakdown [21]. Consequently, before being released into the environment, efficient treatment of wastewater with dye is absolutely vital.

3. Dye Removal Adsorbent Materials

Many different adsorbent materials have been looked at for dye removal from aqueous solutions. Major types of adsorbents together with their benefits and drawbacks are given in this part.

3.1 Activated Carbon:

With its high surface area, porous structure, and adaptability, activated carbon (AC) is among the most often utilized adsorbent for dye removal [22]. By physical or chemical activation techniques, several carbonaceous precursors—coal, coconut shells, wood, etc.—can be generated from AC. AC's surface chemistry, pore size distribution, and specific surface area all affect its adsorption capability.

Advantages:

- High adsorption capacity for a wide range of dyes
- Well-established production methods
- Possibility of regeneration and reuse

Limitations:

- High production cost
- Challenges in regeneration for some dye-AC systems
- Non-selective adsorption

3.2 Agricultural Wastes and Byproducts

Low-cost biosorbents derived from agricultural wastes and byproducts have gained attention as economical alternatives to activated carbon [23]. Some examples include rice husk, wheat straw, coconut coir, orange peel, banana peel, etc. These materials are abundant, renewable, and often require minimal processing.

Advantages:

- Low cost and wide availability
- Environmentally friendly
- Presence of various functional groups aiding adsorption

Limitations:

- Lower adsorption capacity compared to activated carbon
- Potential leaching of organic compounds
- Variability in composition and properties

3.3 Clay Minerals

Natural and modified clay minerals like montmorillonite, kaolinite, bentonite, and sepiolite have been explored as effective adsorbents for dye removal [24]. Their layered structure, high surface area, and ion exchange properties make them suitable for adsorption applications.

Advantages:

- Low cost and abundance
- High adsorption capacity for cationic dyes
- Possibility of modification to enhance performance

Limitations:

- Lower efficiency for anionic dyes
- Challenges in separation after adsorption

3.4 Industrial Byproducts and Wastes

Fly ash, red mud, blast furnace slag, and metal hydroxide sludge are among the low-cost adsorbents [25]. These materials have functional groups for dye adsorption and high surface areas.

Advantages:

- Waste utilization and valorization
- Low cost
- Suitable for treating industrial effluents

Limitations:

- Potential leaching of heavy metals
- Variability in composition
- Limited regeneration potential

3.5 Nanomaterials

Recent breakthroughs in nanotechnology have produced effective dye adsorbent nanomaterials [26]. Nanocomposites, graphene oxide, metal/metal oxide nanoparticles, and carbon nanotubes. Their large surface area to volume ratio and unique physicochemical features improve adsorption.

Advantages:

- Very high adsorption capacity
- Rapid adsorption kinetics
- Possibility of magnetic separation (for magnetic nanoparticles)

Limitations:

- High production cost
- Potential environmental and health risks
- Challenges in large-scale application

3.6 Metal-Organic Frameworks (MOFs)

Metal ions/clusters coupled with organic ligands form porous crystalline MOFs [27]. The high surface area, variable pore size, and functionalization options make them excellent dye removal adsorbents.

Advantages:

- Exceptionally high surface area and porosity
- Tunable structure and functionality
- Potential for selective adsorption

Limitations:

- High synthesis cost
- stability issues in aqueous media

- Challenges in regeneration

3.7 Conducting Polymers

Conducting polymers like polyaniline, polypyrrole, and their composites have emerged as effective adsorbents for dye removal [28]. Their unique electronic structure, ease of synthesis, and possibility of functionalization offer advantages in adsorption applications.

Advantages:

- High adsorption capacity
- Possibility of electro-regeneration
- Facile synthesis and modification

Limitations:

- Relatively high cost
- Potential degradation during regeneration
- Limited studies on long-term stability

Table 2 summarizes the adsorption capacities of various adsorbents for some common dyes.

Table 2: Adsorption capacities of different adsorbents for dye removal

Adsorbent	Dye	Adsorption capacity (mg/g)	Reference
Activated carbon	Methylene blue	400	[29]
Rice husk	Congo red	38.2	[30]
Montmorillonite	Rhodamine B	188.7	[31]
Fly ash	Reactive black 5	20.9	[32]
Graphene oxide	Methylene blue	714	[33]
MIL-101(Cr) MOF	Methyl orange	337	[34]
Polyaniline nanotubes	Acid green 25	625	[35]

4. Adsorption Mechanisms and Influencing Factors

4.1 Adsorption Mechanisms

Depending on the characteristics of the adsorbent and dye molecules, different processes can drive dyes' adsorption onto solid adsorbents [36]. The principal systems consist of:

Weak van der Waals interactions between the adsorbent surface and dye molecules characterise physical adsorption, sometimes known as physisorption.

Chemical adsorption, sometimes known as chemisorption, is the development of chemical bonds between the adsorbent and adsorbate.

Attractions between oppositely charged adsorbent surface and dye ions are electrostatic.

Hydrogen bonding: Development of interactions between dye molecules' functional groups on the adsorbent

Occur between aromatic rings in the dye structure and π-electrons on the adsorbent surface: π-π interactions.

Replacement of dye ions from the solution with ions on the adsorbent surface is ion exchange.

Many times, several mechanisms contribute concurrently to the total adsorption process.

4.2 Components Affecting Adsorption

Several elements influence the adsorption of dyes onto solid adsorbents [37,38]:

pH: Soluón pH affects surface charge of the adsorbent and ionizing of dye molecules, therefore influencing electrostatic interactions.

Higher temperatures often raise adsorption rate but may lower adsorption capacity in exothermic processes.

Higher starting concentrations usually translate into higher adsorption capacity but less removal efficiency.

Adsorption increases with time until equilibrium is attained.

Amount of the adsorbent: Though they may lower adsorption capacity per unit mass, higher adsorbent dosages improve general removal efficiency.

Smaller particle sizes usually translate into better adsorption because of their higher surface area.

Salts can influence electrostatic interactions and fight for adsorption sites, therefore influencing ionic strength.

Other ions in a solution could fight with dye molecules for adsorption sites.

Good interaction between adsorbent and dye molecules guarantees correct mixing speed.

Designing effective treatment systems and maximizing adsorption processes depend on an awareness of these elements.

5. Thermodynamics, Isotherms, and Adsorption Kinetics

5.1 Kinetic Behavior of Adsorption

Adsorption kinetics [39] help to understand the adsorption mechanism and define the rate of dye absorption by the adsorbent. Typical kinetic models comprise:

First-order pseudo-model

pseudo second-order model

Model of intraparticle diffusion

Elowitz model

Suggesting chemisorption as the rate-limiting phase [40], the pseudo-second-order model often shows the greatest fit for dye adsorption data.

5.2 Isotherms of Adsorption

At constant temperature, adsorption isotherms explain the equilibrium relationship between dye adsorbed amount and dye concentration in solution [41]. Usually used isotherm models consist of:

- Lang muir isotherm
- Freundicative isotherm
- Temkin isotropism
- The isotherm Dubinin-Radushkevich

Most often used models for dye adsorption systems are Langmuir and Freundlich ones. Whereas the Freundlich model accounts for multilayer adsorption on heterogeneous surfaces [42], the Langmuir model assumes monolayer adsorption on a homogeneous surface.

5.3 Thermal Dynamics

Thermodynamic parameters reveal the type and feasibility of the adsorption process [43]. Important criteria consist in:

Change in Gibbs free energy, $\Delta G°$

$\Delta H°$, the enthalpy change

Delta S°, entropy change

While positive $\Delta H°$ shows endothermic character of the process, negative $\Delta G°$ values indicate spontaneous adsorption. Positive $\Delta S°$ denotes more unpredictability at the solid-solution contact during adsorption [44].

6. Newadsorbents and Emerging Trends

Development of new adsorbents and hybrid systems to improve dye removal efficiency has lately received much attention. Some newly developing trends consist in:

6.1 Magnetic Attractives

By incorporating magnetic characteristics into adsorbents, simple separation following adsorption under an external magnetic field is made possible [45]. Among these are magnetic biochar, Fe3O4 nanoparticles, and magnetic activated carbon. These materials address a main difficulty in practical applications by combining high adsorption capacity with easy separation.

6.2 Nanoocomposites

Combining many components in nanocomposites produces synergistic effects for maximum dye removal [46]. Among the examples are hybrids between carbon nanotube/metal organic framework and polymer/clay nanocomposites, graphene oxide/metal oxide composites. Often when compared to single components, these materials show better adsorption capability, selectivity, and stability.

6.3 Three-dimensional printed adsorbents

Adsorbent production with regulated porosity, surface area, and usefulness [47] is made possible by 3D printing technology. This method enables customizing of adsorbents for certain dye removal uses. Among those are metal-organic frameworks, zeolites, and 3D-printed activated carbon.

6.4 Biologically based nanocomposites

Combining nanoparticles with bio-based materials presents a sustainable method for producing effective adsorbents [48]. Among the examples are lignin-based nanocomposites, cellulose nanocrystal/graphene oxide composites, and chitosan/metal oxide nanoparticles. These materials mix the benefits of nanoparticles' improved adsorbing qualities with renewable resources.

6.5 Adsorbents with Stimulus-Response

Controlled adsorption and dye release are made possible by development of smart adsorbents responding to external stimuli including pH, temperature, or light [49]. Thermo-responsive polymers, pH-sensitive hydrogels, and photo-responsive materials are few examples. Easy regeneration and selective removal are possibilities presented by these adsorbents.

7. Adsorbents' Regeneration and Reusability

Development of economically feasible and sustainable dye removal methods depends on regeneration and reuse of spent adsorbents [50]. Common approaches of regeneration consist in:

- Thermal therapy
- Acid, base, or organic solvent desorption in chemistry
- Electrochemical regeneration
- Treatment with ultrasonic waves
- photocatalytic rejuvenation

The adsorbent-dye system, financial concerns, and environmental effects determine the regeneration technique chosen. Evaluating several adsorption-desorption cycles helps one to evaluate the reusability and long-term stability of adsorbents.

8. Difficulties and Future Viewpoints

Though adsorptive dye removal has advanced significantly, various difficulties still exist for mass use.

- Affordable manufacturing of top-notch adsorbents
- Target dye selectivity in sophisticated wastewater matrices
- Effective wasted adsorbent management and renewal

- scaling laboratory findings for use in industry
- Long-term stability and performance under practical settings
- Environmental and health effects of adsorbent based on nanomaterials
- Testing method standardization for equitable comparison of adsorbents
- Future studies aimed at tackling these issues could have as their focus:
- Creation from waste products low-cost, sustainable adsorbents
- Design of multifunctional adsorbents for simultaneous pollution removal including colors
- Integration of alternative treatment technologies with adsorption for improved performance
- Utilising machine learning and artificial intelligence for process optimisation and adsorbent design
- Detailed investigations on structure-property correlations and adsorption mechanisms

Adsorption-based treatment system life cycle analysis and techno-economic study

investigating fresh regeneration techniques to extend adsorbent lifetime

9. Conclusions

Because of its simplicity, efficiency, and adaptability, adsorption has become a quite promising method for color elimination from wastewater. Emphasizing on new adsorbent materials, adsorption mechanisms, and developing trends, this analysis gave a thorough picture of current developments in adsorptive dye removal.

Important results comprise:

From low-cost agricultural wastes to cutting-edge nanomaterials and composites, a broad spectrum of adsorbents has been created.

Maximizing removal efficiency depends on a knowledge of adsorption mechanisms and affecting factors.

Enhanced performance and simpler separation are provided by newly developing trends like magnetic adsorbents, nanocomposites, and stimuli-responsive materials.

Sustainable and cheap color removal techniques depend on the adsorbents being regenerated and reused.

Scaling up laboratory findings and guaranteeing long-term stability under practical conditions still present difficulties.

Development of affordable, sustainable adsorbents with great selectivity and regeneration capacity should be the main priorities of next studies. More effective and solid dye removal systems could result from combining adsorption with other treatment technologies and using modern modeling tools. Dealing with the found difficulties and investigating alternative paths will open the path for general application of adsorption-based technologies for treatment of industrial wastewater.

References

[1] F. Lu, D. Astruc, Nanocatalysts and other nanomaterials for water remediation from organic pollutants, Coord. Chem. Rev. 408 (2020) 213180. https://doi.org/10.1016/j.ccr.2020.213180.

[2] J.K.H. Wong, H.K. Tan, S.Y. Lau, P.S. Yap, M.K. Danquah, Potential and challenges of enzyme incorporated nanotechnology in dye wastewater treatment: A review, J. Environ. Chem. Eng. 7 (2019) 103261. https://doi.org/10.1016/j.jece.2019.103261.

[3] Y. Zhou, J. Lu, Y. Zhou, Y. Liu, Recent advances for dyes removal using novel adsorbents: A review, Environ. Pollut. 252 (2019) 352–365. https://doi.org/10.1016/j.envpol.2019.05.072.

[4] M. Rafatullah, O. Sulaiman, R. Hashim, A. Ahmad, Adsorption of methylene blue on low-cost adsorbents: A review, J. Hazard. Mater. 177 (2010) 70–80. https://doi.org/10.1016/j.jhazmat.2009.12.047.

[5] N.R.J. Hynes, J.S. Kumar, H. Kamyab, J.A.J. Sujana, O.A. Al-Khashman, Y. Kuslu, A. Ene, B. Suresh Kumar, Modern enabling techniques and adsorbents based dye removal with sustainability concerns in textile industrial sector -A comprehensive review, J. Clean. Prod. 272 (2020) 122636. https://doi.org/10.1016/j.jclepro.2020.122636.

[6] C. Ogugbue, T. Sawidis, Bioremediation and detoxification of synthetic wastewater containing triarylmethane dyes by Aeromonas hydrophila isolated from industrial effluent, Biotechnol. Res. Int. (2011). https://www.hindawi.com/archive/2011/967925/ (accessed December 4, 2020).

[7] E.N. Zare, A. Motahari, M. Sillanpää, Nanoadsorbents based on conducting polymer nanocomposites with main focus on polyaniline and its derivatives for removal of heavy metal ions/dyes: A review, Environ. Res. 162 (2018) 173–195. https://doi.org/10.1016/j.envres.2017.12.025.

[8] S. Benkhaya, S. M' rabet, A. El Harfi, A review on classifications, recent synthesis and applications of textile dyes, Inorg. Chem. Commun. 115 (2020) 107891. https://doi.org/10.1016/j.inoche.2020.107891.

[9] E. Guerra, M. Llompart, C. Garcia-Jares, Analysis of dyes in cosmetics: Challenges and recent developments, Cosmetics. 5 (2018) 47. https://doi.org/10.3390/COSMETICS5030047.

[10] K. Yamjala, M.S. Nainar, N.R. Ramisetti, Methods for the analysis of azo dyes employed in food industry - A review, Food Chem. 192 (2016) 813–824. https://doi.org/10.1016/j.foodchem.2015.07.085.

[11] B. Lellis, C.Z. Fávaro-Polonio, J.A. Pamphile, J.C. Polonio, Effects of textile dyes on health and the environment and bioremediation potential of living organisms, Biotechnol. Res. Innov. 3 (2019) 275–290. https://doi.org/10.1016/j.biori.2019.09.001.

[12] B. Gupta, T. Priya, B. Kumar Mishra, Augmentation of the coagulation activity of alum using a porous bio-flocculant for the remediation of trihalomethanes-generating hydrophobic natural organic matter, Environ. Eng. Res. 26 (2021) 200234. https://doi.org/10.4491/eer.2020.234.

[13] T. Priya, A. Tarafdar, B. Gupta, B.K. Mishra, Effect of bioflocculants on the coagulation activity of alum for removal of trihalomethane precursors from low turbid water, J. Environ. Sci. (China). 70 (2018). https://doi.org/10.1016/j.jes.2017.09.019.

[14] A. Majumder, B. Gupta, A.K. Gupta, Pharmaceutically active compounds in aqueous environment: A status, toxicity and insights of remediation, Environ. Res. 176 (2019) 108542. https://doi.org/10.1016/j.envres.2019.108542.

[15] V.K. Parida, D. Saidulu, A. Majumder, A. Srivastava, B. Gupta, A.K. Gupta, Emerging contaminants in wastewater : A critical review on occurrence , existing legislations , risk

assessment , and sustainable treatment alternatives, J. Environ. Chem. Eng. 9 (2021) 105966. https://doi.org/10.1016/j.jece.2021.105966.
[16] A. Srivastava, B. Gupta, A. Majumder, A.K. Gupta, S.K. Nimbhorkar, A comprehensive review on the synthesis, performance, modifications, and regeneration of activated carbon for the adsorptive removal of various water pollutants, J. Environ. Chem. Eng. (2021) 106177. https://doi.org/10.1016/J.JECE.2021.106177.
[17] A. Srivastava, V.K. Parida, A. Majumder, B. Gupta, A.K. Gupta, Treatment of saline wastewater using physicochemical, biological, and hybrid processes: Insights into inhibition mechanisms, treatment efficiencies and performance enhancement, J. Environ. Chem. Eng. 9 (2021) 105775. https://doi.org/10.1016/j.jece.2021.105775.
[18] B. Gupta, A.K. Gupta, Photocatalytic performance of 3D engineered chitosan hydrogels embedded with sulfur-doped C3N4/ZnO nanoparticles for Ciprofloxacin removal: Degradation and mechanistic pathways, Int. J. Biol. Macromol. 198 (2022) 87–100. https://doi.org/10.1016/J.IJBIOMAC.2021.12.120.
[19] B. Gupta, A.K. Gupta, P.S. Ghosal, S. Lal, D. Saidulu, A. Srivastava, M. Upadhyay, Recent advances in application of moving bed biofilm reactor for wastewater treatment: Insights into critical operational parameters, modifications, field-scale performance, and sustainable aspects, J. Environ. Chem. Eng. 10 (2022) 107742. https://doi.org/10.1016/J.JECE.2022.107742.
[20] B. Gupta, R.S. Ambekar, R.M. Tromer, P.S. Ghosal, R. Sinha, A. Majumder, P. Kumbhakar, P.M. Ajayan, D.S. Galvao, A.K. Gupta, C.S. Tiwary, Development of a schwarzite-based moving bed 3D printed water treatment system for nanoplastic remediation, RSC Adv. 11 (2021) 19788–19796. https://doi.org/10.1039/D1RA03097C.
[21] P. Ghosal, B. Gupta, R.S. Ambekar, M.M. Rahman, P.M. Ajayan, N. Aich, A.K. Gupta, C.S. Tiwary, 3D Printed Materials in Water Treatment Applications, Adv. Sustain. Syst. (2021) 2100282. https://doi.org/10.1002/ADSU.202100282.
[22] S. Mor, K. Ravindra, N.R. Bishnoi, Adsorption of chromium from aqueous solution by activated alumina and activated charcoal, Bioresour. Technol. 98 (2007) 954–957. https://doi.org/10.1016/J.BIORTECH.2006.03.018.
[23] K.K. Singh, R.C. Vaishya, Municipal Wastewater Treatment uses Vertical Flow Followed by Horizontal Flow in a Two-Stage Hybrid-Constructed Wetland Planted with Calibanus hookeri and Canna indica (Cannaceae), Water. Air. Soil Pollut. 233 (2022) 1–12. https://doi.org/10.1007/S11270-022-05984-0/FIGURES/9.
[24] N.S. Maurya, A.K. Mittal, Applicability of immobilized wood-rotting fungal biomass for biosorption of basic dye Alcian Blue, Water Sci. Technol. 59 (2009) 2073–2079. https://doi.org/10.2166/WST.2009.866.
[25] N.S. Maurya, A.K. Mittal, Kinetic model for the immobilised biosorbents: Uptake of cationic dyes, Chem. Eng. J. 254 (2014) 571–578. https://doi.org/10.1016/J.CEJ.2014.05.064.
[26] C. Manera, A.P. Tonello, D. Perondi, M. Godinho, Adsorption of leather dyes on activated carbon from leather shaving wastes: kinetics, equilibrium and thermodynamics studies, Environ. Technol. (United Kingdom). 40 (2019) 2756–2768. https://doi.org/10.1080/09593330.2018.1452984.
[27] K. Rachna, A. Agarwal, N.. Singh, Rice husk and Sodium hydroxide activated Rice husk for removal of Reactive yellow dye from water, Mater. Today Proc. 12 (2019) 573–580. https://doi.org/10.1016/j.matpr.2019.03.100.
[28] N. Yadav, V.K. Garg, A.K. Chhillar, J.S. Rana, Detection and remediation of pollutants to maintain ecosustainability employing nanotechnology: A review, Chemosphere. 280 (2021). https://doi.org/10.1016/J.CHEMOSPHERE.2021.130792.
[29] B. Gupta, A.K. Gupta, C.S. Tiwary, P.S. Ghosal, A multivariate modeling and experimental realization of photocatalytic system of engineered S-C3N4/ZnO hybrid for ciprofloxacin removal: Influencing factors and degradation pathways, Environ. Res. (2020) 110390.

https://doi.org/10.1016/j.envres.2020.110390.
[30] B. Gupta, A.K. Gupta, P.S. Ghosal, C.S. Tiwary, Photo-induced degradation of bio-toxic Ciprofloxacin using the porous 3D hybrid architecture of an atomically thin sulfur-doped g-C3N4/ZnO nanosheet, Environ. Res. 183 (2020) 109154. https://doi.org/10.1016/j.envres.2020.109154.
[31] S.K. Kuila, D.K. Gorai, B. Gupta, A.K. Gupta, C.S. Tiwary, T.K. Kundu, Lanthanum ions decorated 2-dimensional g-C3N4 for ciprofloxacin photodegradation, Chemosphere. (2020) 128780. https://doi.org/10.1016/j.chemosphere.2020.128780.
[32] K.G. Pavithra, S.K. P., V. Jaikumar, S.R. P., Removal of colorants from wastewater: A review on sources and treatment strategies, J. Ind. Eng. Chem. 75 (2019) 1–19. https://doi.org/10.1016/j.jiec.2019.02.011.
[33] CPHEEO, Manual on Sewerage and Sewage Treatment Systems - 2013:Central Public Health & Environmental Engineering Organisation (CPHEEO), Govt of India, 2013. http://cpheeo.gov.in/cms/manual-on-sewerage-and-sewage-treatment.php (accessed August 9, 2020).
[34] T.H. Kim, Y. Lee, J. Yang, B. Lee, C. Park, S. Kim, Decolorization of dye solutions by a membrane bioreactor (MBR) using white-rot fungi, Desalination. 168 (2004) 287–293. https://doi.org/10.1016/j.desal.2004.07.011.
[35] S. Dutta, K. Manna, S.K. Srivastava, A.K. Gupta, M.K. Yadav, Hollow Polyaniline Microsphere/Fe3O4 Nanocomposite as an Effective Adsorbent for Removal of Arsenic from Water, Sci. Rep. 10 (2020) 1–14. https://doi.org/10.1038/s41598-020-61763-z.
[36] V.K. Gupta, Suhas, I. Ali, V.K. Saini, Removal of Rhodamine B, Fast Green, and Methylene Blue from Wastewater Using Red Mud, an Aluminum Industry Waste, Ind. Eng. Chem. Res. 43 (2004) 1740–1747. https://doi.org/10.1021/ie034218g.
[37] K. Shen, M.A. Gondal, Removal of hazardous Rhodamine dye from water by adsorption onto exhausted coffee ground, J. Saudi Chem. Soc. 21 (2017) S120–S127. https://doi.org/10.1016/j.jscs.2013.11.005.
[38] H. Chafai, M. Laabd, S. Elbariji, M. Bazzaoui, A. Albourine, Study of congo red adsorption on the polyaniline and polypyrrole, J. Dispers. Sci. Technol. 38 (2017) 832–836. https://doi.org/10.1080/01932691.2016.1207185.
[39] N. Mohammadi, H. Khani, V.K. Gupta, E. Amereh, S. Agarwal, Adsorption process of methyl orange dye onto mesoporous carbon material-kinetic and thermodynamic studies, J. Colloid Interface Sci. 362 (2011) 457–462. https://doi.org/10.1016/j.jcis.2011.06.067.
[40] B.M. Thamer, A. Aldalbahi, M. Moydeen A, H. El-Hamshary, A.M. Al-Enizi, M.H. El-Newehy, Effective adsorption of Coomassie brilliant blue dye using poly(phenylene diamine)grafted electrospun carbon nanofibers as a novel adsorbent, Mater. Chem. Phys. 234 (2019) 133–145. https://doi.org/10.1016/j.matchemphys.2019.05.087.
[41] C. Cojocaru, P. Samoila, P. Pascariu, Chitosan-based magnetic adsorbent for removal of water-soluble anionic dye: Artificial neural network modeling and molecular docking insights, Int. J. Biol. Macromol. 123 (2019) 587–599. https://doi.org/10.1016/j.ijbiomac.2018.11.080.
[42] M.F. Chowdhury, S. Khandaker, F. Sarker, A. Islam, M.T. Rahman, M.R. Awual, Current treatment technologies and mechanisms for removal of indigo carmine dyes from wastewater: A review, J. Mol. Liq. 318 (2020) 114061. https://doi.org/10.1016/j.molliq.2020.114061.
[43] D.A. Yaseen, M. Scholz, Textile dye wastewater characteristics and constituents of synthetic effluents: a critical review, Int. J. Environ. Sci. Technol. 16 (2019) 1193–1226. https://doi.org/10.1007/s13762-018-2130-z.
[44] A. Gičević, L. Hindija, A. Karačić, Toxicity of azo dyes in pharmaceutical industry, in: IFMBE Proc., Springer Verlag, 2020: pp. 581–587. https://doi.org/10.1007/978-3-030-17971-7_88.
[45] M.T. Yagub, T.K. Sen, S. Afroze, H.M. Ang, Dye and its removal from aqueous solution by adsorption: A review, Adv. Colloid Interface Sci. 209 (2014) 172–184.

https://doi.org/10.1016/j.cis.2014.04.002.
[46] T. Robinson, G. McMullan, R. Marchant, P. Nigam, Remediation of dyes in textile effluent: A critical review on current treatment technologies with a proposed alternative, Bioresour. Technol. 77 (2001) 247–255. https://doi.org/10.1016/S0960-8524(00)00080-8.
[47] J. Garvasis, A.R. Prasad, K.O. Shamsheera, P.K. Jaseela, A. Joseph, Efficient removal of Congo red from aqueous solutions using phytogenic aluminum sulfate nano coagulant, Mater. Chem. Phys. 251 (2020) 123040. https://doi.org/10.1016/j.matchemphys.2020.123040.
[48] M.F. Abid, M.A. Zablouk, A.M. Abid-Alameer, Experimental study of dye removal from industrial wastewater by membrane technologies of reverse osmosis and nanofiltration, Iran. J. Environ. Heal. Sci. Eng. 9 (2012) 1–9. https://doi.org/10.1186/1735-2746-9-17.
[49] R. Singh, M.K. Sinha, M.K. Purkait, Stimuli responsive mixed matrix polysulfone ultrafiltration membrane for humic acid and photocatalytic dye removal applications, Sep. Purif. Technol. 250 (2020) 117247. https://doi.org/10.1016/j.seppur.2020.117247.
[50] V. Katheresan, J. Kansedo, S.Y. Lau, Efficiency of various recent wastewater dye removal methods: A review, J. Environ. Chem. Eng. 6 (2018) 4676–4697. https://doi.org/10.1016/j.jece.2018.06.060.