

Sustainable Wastewater Treatment using Magnetic Zeolites as Recyclable Adsorbents: A Review

Navneet Kumar^{1*} and Himanshu Yadav²

Author's Affiliations:

¹Associate Professor, Department of Chemistry, Faculty of Engineering, Teerthanker Mahaveer University, Moradabad- 244001 Uttar Pradesh, India

E-mail: navkchem@gmail.com, drnavneet.engineering@tmu.ac.in,

²Assistant Professor, Department of Forensic Science, School of Allied Health Sciences, Sharda University, Greater Noida- 201310 Uttar Pradesh, India

***Corresponding Author: Navneet Kumar**, Associate Professor, Department of Chemistry, Faculty of Engineering, Teerthanker Mahaveer University, Moradabad, Uttar Pradesh 244001, India.

E-mail: navkchem@gmail.com

ABSTRACT

An open foundation structure of 3-dimensional tetrahedron units is produced when oxygen atoms are dispersed inside the silicate and aluminium tetrahedral framework to form zeolite, a kind of crystalline silicate that incorporates aluminium. Zeolite that is magnetic, is a special kind of adsorbent that is magnetic is made by merging the all-adhesion qualities of zeolite using the magnetic qualities of magnetic oxides. Because magnetic elements may be easily removed from solutions, the synthesis of magnetically modified zeolites has attracted a lot of attention recently. According to recent studies on the application of magnetic zeolite in treatment of wastewater, heavy metals like Cr^{6+} , Cu^{2+} , and Pb^{2+} , methylene blue like dyes, & cephalixin like antibiotics may all be extracted from water using a simple magnetic method. This review gives an in-depth insight into the possible positive outcomes of magnetic zeolites applications in the treatment of wastewater.

Keywords: Zeolites, Magnetic Oxides, Adsorption, Synthesis, Dyes.

Received on 23.06.2026, Revised on 20.08.2026, Accepted on 11.09.2026

How to cite this article: Kumar N. and Yadav H. Synthesis and Sustainable Wastewater Treatment using Magnetic Zeolites as Recyclable Adsorbents: A Review. *Bulletin of Pure and Applied Sciences-Chemistry*, 2026; 45C (2), 13-22.

1. INTRODUCTION

Many highly advanced applications are being sorted today to address environmental issues. Because of its adsorption and separation capabilities, the application of magnetic particle technology has drawn a lot of interest lately. A unique, energy-efficient magnetic adsorbent is

created when the magnetic capabilities of magnetic oxides and the adsorption properties of zeolite combine. Figure 1 shows the recent 20 years trend on magnetic zeolites that highlights the rapid increase in research interest and popularity.

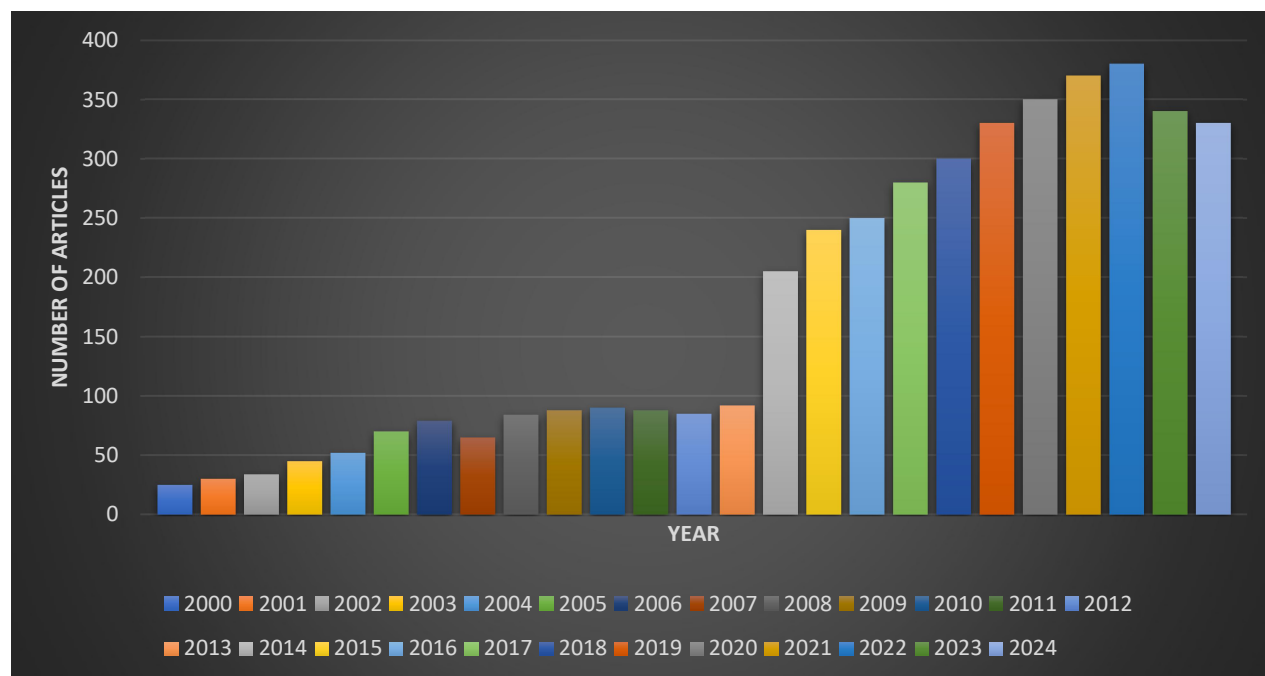


Figure 1: Articles published on the magnetic-zeolites between year 2000 & 2024. Web of Science is the source.

Because of their small area of the surface and poor sorption ability, Magnetic elements are limited to the sorption of sewage harmful substances and can only be further removed

from the medium by a straightforward magnetic process. Table 1 shows the different classification of magnetic materials and their application.

Table 1: Magnetic Materials Classification

Category of Magnetic Material	Characteristic	Application	Example
Ferromagnetic Material	Excellent permeability. Under an external magnetic field, strong magnetisation is produced and may be sustained.	Magnetic recording medium, transformer, motor, and permanent magnet	Nickel, cobalt, iron, and metal oxide
Antiferromagnetic material	The total magnetisation tends to zero and the moments of magnetism are organised in reversible / partial reversible phase.	Materials that absorb electromagnetic waves, spintronics, magnetic coatings, magnetic storage devices, and magnetic core materials	Other ferrites mgFe_2O_4 , ZnFe_2O_4 , CoFe_2O_4 , MnO , and Cr_2O_3
Paramagnetic material	The magnetisation is positive and has a low intensity when exposed to an external magnetic field. As the	Magnetic resonance imaging (MRI), physical research	Aluminum, sodium, and titanium

	temperature rises, the magnetisation diminishes.		
Diamagnetic material	generate low magnetisation within the opposite path of the external magnetic field.	High-precision test, magnetic shielding	Copper, graphite
Soft magnetic material	Magnetisation is simple and demagnetisation occurs quickly; the magnetism maintained is modest and the permeability is high.	Electromagnet, transformer, inductor	Sheet of Silicon steel, the primary substance is iron powder.
Hard magnetic material	Strong magnetism persists even after the external magnetic field is removed due to high residual magnetisation and coercivity.	Permanent magnet, magnetic sensor	NdFeB, AlNiCo

By creating magnetised zeolite compounds based on zeolite, clay, and activated carbon, these restrictions can be addressed. Numerous pollutants, including antibiotics [1], heavy metals [2,3], and dyes [3], have been shown to adsorb, according to recent literature reports. Due to the size of their surfaces, their high adsorption capacity, and net negative charge from their channel structure, zeolites are readily drawn to cationic dyes and heavy metals.

By creating magnetised zeolite blends based on zeolite, volcanic clay, and charcoal, these restrictions can be addressed. Numerous pollutants, including antibiotics [1], heavy metals [2,3], and dyes [3], have been shown to adsorb, according to recent literature reports. Zeolites are easily attracted to metals that are heavy and cationic dyes because of large area of surface, better adsorption capacity, & net -ve charge from their structure. Furthermore, because of extremely high levels of toxicity and carcinogenesis, dyes released into the ecological system without sufficient remediation can pose a risk to health of marine life and also for humans [4]. Many adsorbents have been utilized in water pollution management technology to absorb dyes and ions of heavy metals. Recent research has indicated that the future of iron nanoparticles applicability for effective

remediation of contaminants. Excellent adsorption for heavy metals including As^{+3} , As^{+5} , Cr^{+6} , and Pb^{+2} as well as a variety of dyes like methylene blue, indigo carmine, and congo red has been seen in them [5,6]. However, the primary disadvantage of this type of magnetic adsorbent is that iron nanoparticles easily oxidize or dissolve in acidic media, making recycling them difficult [7,8]. In order to regulate the particle sizes and prevent such materials from oxidizing, different solid substrates were subsequently introduced in order to address these shortcomings. Various techniques for employing magnetic zeolite to remove these contaminants are outlined. A thorough discussion of the numerous methods of synthesis for zeolites that are magnetic in nature as well as adsorbent has been held. The research indicates that a number of techniques have been investigated to construct magnetically modified zeolite, comprising the inclusion of Fe_3O_4 nanoparticles during synthesis [2,3,9], covering the zeolite's surface with ferric oxide, then reducing and precipitating the iron oxide on the zeolite's surface [10,11]. The synthetic procedures mentioned above have showcased that the inclusion of oxides of iron does not decrease the zeolite's sorption efficiency.

2. MAGNETIC ZEOLITE

2.1. Characteristics and Synthesis Techniques

A zeolite magnetic in nature is a contemporary type of magnetized sorbent that combines the magnetic and adsorption characteristics of iron oxides. Figure 2 shows the structure of magnetic zeolite. High area of surface, very high coercivity, diminished toxicity, and great chemical stability are characteristics of iron oxide (Fe_3O_4) nanoparticles [12]. The Fe_3O_4 elements can be readily isolated from the suspension in the magnetic field presence because of their magnetized character. Numerous techniques exist for the production of magnetic Fe_3O_4 , including the sol-gel method [13], hydrothermal treatment [2,3], micro-emulsion technique [14], electrochemical procedure [15], and process of co-precipitation [2,3]. The process of hydrothermal sterilization approach is one of these that works well for producing nano-size Fe_3O_4 particles quickly [16]. Zeolites containing iron have been thoroughly

investigated because of their exceptional catalytic activity, which includes Ammonia-mediated selective reduction of nitrogen oxides [17] and CH_4 hydroxylation [18].

The turning on of the additional lattice of iron linked to the ion exchange sites that are active as a result of an imposed limited coordination geometry by the telometella complex is responsible for this extraordinary catalytic activity [18]. Numerous techniques have been investigated to produce magnetically modified zeolites, including Fe_3O_4 nanoparticle incorporation during polymerization [2,3,9], covering oxides of ferric on the topical layer of the zeolites then diminution [19], and iron crystallization oxide on the topical layer of the zeolites [10,11]. The synthetic procedures mentioned above have demonstrated that the addition of oxides of iron does not decrease the zeolite's efficacy of adsorption.

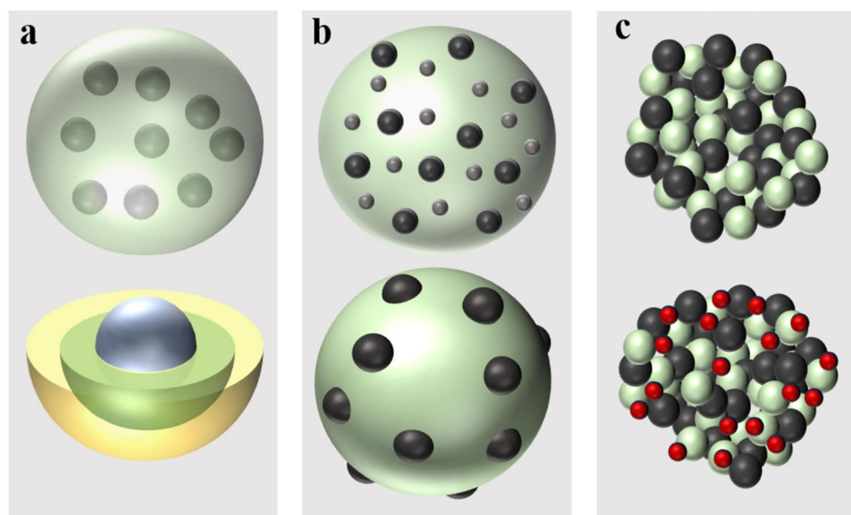


Figure 2: Magnetic zeolite structure classification. (a) Magnetic zeolite structure within. (b) The structure of an external magnetic zeolite. (c) A complex structure of magnetic zeolites.

3. THE USE OF MAGNETITE IN TREATMENT OF EFFLUENT

3.1. Heavy metals

Both aquatic species and humans are severely harmed by water that contains ions of heavy metals. Heavy metals are those that have a

density more than 5 grams % [20]. Chromium, cadmium, lead, arsenic, and mercury, among others are a few examples of the heavy metals emitted by mining, metal manufacture, chemical fertilizers, leather goods, electroplating, dyes, and battery [21]. High exposure to these

hazardous metal ions can harm the kidneys, neurological system, and liver [22]. A small number of these harmful ions of heavy metals cause cancer when the concentration of these ions rises above the threshold levels. Pb^{+2} , Hg^{+2} , As^{+3} are among the very hazardous elements found in trace metals, and they can cause severe health issues in children, such as mental and learning difficulties, behavioral problems, hearing impairments, etc. [23]. In an effort to mitigate the ecological effects of these hazardous metals, some studies have focused on removing heavy metals from sources of drinking water and industrial effluent. A few methods for removing the heavy metals include adsorption, electrocoagulation, & microbiological remediation using various materials of adsorbent in nature as zeolites or activated charcoal etc. The very one such of the inexpensive, eco-friendly, and adsorbent of reusable nature that has demonstrated exceptional efficacy in the elimination of heavy metals is magnetized zirconate. [2,3] Various studies have documented the successful production of zeolites that are magnetic in nature by incorporating Fe_3O_4 into zeolite NaA, which was hydrothermally produced from natural kaolin after the zeolite aged.

In the synthesis of zeolite NaA, a specific set of experimental conditions was identified as the most favorable for obtaining high crystallinity and structural stability. The optimized molar ratios were determined to be $\text{SiO}_2/\text{Al}_2\text{O}_3 = 2.3$, ensuring an appropriate balance between silica and alumina in the framework; $\text{Na}_2\text{O}/\text{SiO}_2 = 1.4$, which provides sufficient alkalinity for crystal growth; and $\text{H}_2\text{O}/\text{Na}_2\text{O} = 50$, offering the necessary hydration for nucleation and crystal development. Under these conditions, maintaining a crystallization temperature of 950°C for a period of 8 hours yielded well-defined zeolite NaA crystals. This illustrates that these parameters are instrumental in ensuring that the development of zeolite phases is successfully attained and that the physicochemical characteristics of such phases become optimized through manipulation for practical application within industry. The loading of Fe_3O_4 went up from 2.1% to 4.7% while at the same time magnetization increased from 225.00-

m^3kg^{-1} , but CEC increased from 3.20-2.880 mmol g^{-1} .

The adsorption experiments demonstrated a slight reduction in the limits of zeolite of magnetic nature to remove heavy metals ions as the Fe_3O_4 content increased. Specifically, the uptake of Pb^{2+} decreased from 2.35 to 2.28 mmol g^{-1} , while the adsorption of Cu^{2+} declined from 2.42 to 2.32 mmol g^{-1} when the Fe_3O_4 loading was raised from 0 to 4.7 wt%. Such a slight drop may be reasonably explained by a certain blockage of pores and cavities in the zeolite lattice structure due to the use of iron oxide particles. Notwithstanding such a drop, however, the general adsorption capacity was still maintained above 95% in terms of the two metals under study, which highlights the efficiency of using magnetic zeolites in dealing with heavy metals. Expanding the idea further, previous research works have produced analogous results concerning different pollutants. For example, scientists have created new magnetic zeolite nanomaterials using nanozeolite A and iron oxide, demonstrating high effectiveness in removing radioactive elements. The composite achieved removal efficiencies of approximately 95.2% for Sr^{2+} and 81.4% for Cs^+ , demonstrating its potential in nuclear wastewater treatment [24,19,25-28]. In another investigation, magnetic zeolite was explored for the sorption of chromium (VI) from water-based suspensions. By integrating magnetic zeolite with the natural polymer chitosan through a sol-gel technique, a composite material (MZ-C) was developed with enhanced affinity for Cr (VI). This hybrid sorbent exhibited an impressive 98% removal efficiency, signifying its promise as a sustainable and eco-friendly adsorbent. The magnetic separability is among the major benefits associated with the composite since it can be recovered from the water body and used again in the next cycle for treatment purposes hence saving on costs. Additionally, in experiments conducted by combining zeolites NaY with Fe_2O_3 , it was discovered that the combination has synergistic benefits since the excessive sorption abilities of the zeolites were combined with the magnetic abilities of the iron oxides [29-33]. Not only do such composites retain high efficiency in eliminating toxic metal ions, but they also enable efficient recovery procedures

because of their magnetic properties. Overall, these results indicate that magnetized zeolite-based composites are multi-purpose substances suitable for the elimination of various metallic compounds. Their tunable composition, excellent adsorption performance, and easy magnetic recovery make them strong candidates for large-scale environmental remediation and water purification applications.

3.2. Color

The use of magnetic zeolite composites in the adsorption process for the treatment of wastewater is widespread. The primary benefit of magnetic zeolite composites is their ability to create pollutants and dispose of excessive volume of wastewater within ultra short amount of time. The majority of magnetic particles sold commercially are expensive and unsuitable for use in large scale operations. To remove impurities, inexpensive absorbents like natural zeolite could be magnetically modified. Numerous studies on adsorption of dye through composites of magnetic nature made of oxides of iron, activated charcoal, graphene oxide & magnetic particles have been conducted. However, this review demonstrates the magnetic zeolite composite's adsorption capacity for color elimination from sewage.

3.3. Pharmaceutical waste

Pharmaceutical wastes include vitamins, opioids, and toxic medications are frequently used to treat a variety of ailments in both humans and animals. However, because of their poisonous character, researchers have been interested in them recently. Chronic poisoning can result from such wastes [34]. It has been discovered that traditional treatment methods can remove some of the chemicals found in pharmaceutical effluent. There is an accumulation of leftover pharmaceutical compounds in the treated water as a result of their ineffectiveness in eliminating or degrading all sorts of chemicals [35]. A number of technologies, including membrane filtering [36], ozonation [37], and adsorption by activated carbon [38], have been shown to be effective in eliminating PPCPs, or personal care products and pharmaceuticals, including steroids, cosmetics, analgesics, antimicrobial drugs, & lotions from effluent from pharmaceuticals. Iron

oxide nanomaterials with special qualities (superparamagnetic, large surface area) have been extensively researched lately [39]. Different synthesis processes have been developed to produce nanoparticles of higher quality. Among these modifications, the combination of magnetic nanoparticles with zeolite support demonstrated a high effectiveness of heavy metal elimination [40].

3.4. Additional pollutants

Zeolites present a desirable & economical solution for the disposal of both inorganic & organic toxins. The literature has recently reported about the adhesion of various organic toxins, including, chlorophenols, phenols, antibiotics & pesticides in wastewater. It has been investigated how covering zeolites with magnetic Fe_3O_4 nanoparticles can increase their capacity to adsorb cephalixin. [41]. At an ideal pH of 7 and a temperature of 20°C , a 93 % dissolution effectiveness for cephalixin was attained, with an ultimate binding capacity of 24.9 mg for every gram for organic zeolite covered with nanoparticle of Fe_3O_4 that are magnetic in nature.[42] Efforts made to remove arsenate (a pesticide) from aquatic systems by the nano magnetite Zeolite Composites. A composite including nanoscale magnetite particles was created. Maximum adsorption capacity of 5.2 mg/g was demonstrated by a micro sized natural zeolite mass ratio of 0.30:1.1. Supported nanosized magnetite particles reduce the possibility of infestation with nanoparticles [43] created a new carboxylato-calix composite. The authors of this study [10] utilized covalent bonding between acnes and magnetic zeolites as an adsorbent material to effectively distinct & newborn milk powder & concentrate phenolic antioxidants in advance from juice samples that had higher enrichment elements within the range of 41.9–92.5. High adsorption effectiveness is a result of the vast surface area to volume ratios of magnetic zeolite in comparison to other macroscopic adsorbents. Furthermore, an external magnetic field can be used to easily separate these magnetic composites from aqueous streams. All things considered, the combination of the distinct qualities of magnetite and contemporary technologies is a game-changing instrument for wastewater treatment.

4. CONCLUSION

After the thorough review of the results, it is clear that the zeolites of magnetic in nature are the most trending and lucrative option for the elimination of pollutants from marine systems rather than the conventional adsorbents. These magnetic zeolites not only resemble the increased adsorptions limits but also shows excellent efficiency of regeneration, unlike conventional zeolites which makes them more feasible or sustainable reusable option for the effluent treatment processes. The double strength lies in their capacity to be utilized as reliable, economical, and environmental-friendly resources in tackling large-scale problems. Therefore, the application of such magnetic zeolites in water purification can yield immense benefits to society as well as economy especially when considering the problems of water contamination.

With regard to future developments, the existing literature has identified a number of promising directions. For instance, one area worth mentioning is connected to the application of industrial trash products like the fly ash mixture, clay, & typical red dirt as relatively inexpensive raw materials for manufacturing magnetic zeolites. Red mud should be singled out among these materials because of the inherently high content of iron found in red mud, thus making it a promising raw material for obtaining iron-containing magnetic composites. Such an approach would not only help decrease production costs but would also be sustainable in nature.

REFERENCES

1. AbdulRazak AA, Shakora ZM, Rohani S. Optimizing Biebrich Scarlet removal from water by magnetic zeolite 13X using response surface method. *J Environ Chem Eng*. 2018;6:6175-6183.
2. Liu H, Peng S, Shu L, Chen T, Bao T, Frost RL. Magnetic zeolite NaA: synthesis, characterization based on metakaolin and its application for the removal of Cu²⁺, Pb²⁺. *Chemosphere*. 2013;91:1539-1546.
3. Liu H, Peng S, Shu L, Chen T, Bao T, Frost RL. Effect of Fe₃O₄ addition on removal of ammonium by zeolite NaA. *J Colloid Interface Sci*. 2013;390(1):204-210.
4. Ghaedi M, Mazaheri H, Khodadoust S, Hajati S, Purkait MK. Application of central composite design for simultaneous removal of methylene blue and Pb²⁺ ions by walnut wood activated carbon. *Spectrochim Acta A Mol Biomol Spectrosc*. 2015;135:479-490.
5. Falyouna O, Eljamal O, Maamoun I, Tahara A, Sugihara Y. Magnetic zeolite synthesis for efficient removal of cesium in a lab-scale continuous treatment system. *J Colloid Interface Sci*. 2020;571:66-79.
6. Zhang X, Cheng T, Chen C, Wang L, Deng Q, Chen G, et al. Synthesis of a novel magnetic nano-zeolite and its application as an efficient heavy metal adsorbent. *Mater Res Express*. 2020;7:085007.
7. Liu J, Yu Y, Zhu S. Synthesis and characterization of a magnetic adsorbent from negatively-valued iron mud for methylene blue adsorption. *PLoS One*. 2018;13.
8. Zhu J, Wei S, Chen M, Gu H, Rapole SB, Pallavkar S, et al. Magnetic nanocomposites for environmental remediation. *Adv Powder Technol*. 2013;24:459-467.
9. Cao JL, Liu XW. Magnetic P zeolites: synthesis, characterization and the behavior in potassium extraction from seawater. *Sep Purif Technol*. 2008;63:92-100.
10. Gaffer A, Al Kahlawy AA, Aman D. Magnetic zeolite-natural polymer composite for adsorption of chromium (VI). *Egypt J Pet*. 2017;26:995-999.
11. Oliveira LCA, Petkowicz DI, Smaniotto A, Perghe SBC. Magnetic zeolites: a new adsorbent for removal of metallic contaminants from water. *Water Res*. 2004;38:3699-3704.
12. Cornell RM, Schwertmann U. The Iron Oxides: Structure, Properties, Reactions, Occurrences and Uses. Hoboken (NJ): John Wiley & Sons; 2003.
13. Niznansky D, Viart N, Rehspringer JL. Nanocomposites Fe₂O₃/SiO₂ preparation by sol-gel method and physical properties. *J Sol-Gel Sci Technol*. 1997;8(1-3):615-618.
14. Xiaotun Y, Lingge X, Choon NS, Hardy CSO. Magnetic and electrical properties of

- polypyrrole-coated-Fe₂O₃ nanocomposite particles. *Nanotechnology*. 2003;14(6):624-629.
15. Pascal C, Pascal JL, Favier F, Elidrissi Moubtassim ML, Payen C. Electrochemical synthesis for the control of γ -Fe₂O₃ nanoparticle size: morphology, microstructure, and magnetic behavior. *Chem Mater*. 1999;11(1):141-147.
 16. Ge S, Shi X, Sun K, Li C, Uher C, Baker JR, et al. Facile hydrothermal synthesis of iron oxide nanoparticles with tunable magnetic properties. *J Phys Chem C*. 2009;113(31):13593-13599.
 17. Delahay G, Valade D, Guzmán-Vargas A, Coq B. Selective catalytic reduction of nitric oxide with ammonia on Fe-ZSM-5 catalysts prepared by different methods. *Appl Catal B*. 2005;55(2):149-155.
 18. Snyder BER, Vanelderen P, Bols ML, Hallaert SD, Böttger LH, Ungur L, et al. The active site of low temperature methane hydroxylation in iron-containing zeolites. *Nature*. 2016;536:317-321.
 19. Jiang WJ, Gu L, Li L, Zhang Y, Zhang X, Zhang LJ, et al. Understanding the high activity of Fe-N-C electrocatalysts in oxygen reduction: Fe/Fe₃C nanoparticles boost the activity of Fe-Nx. *J Am Chem Soc*. 2016;138:3570-3578.
 20. Barakat MA. New trends in removing heavy metals from industrial wastewater. *Arab J Chem*. 2011;4(4):361-377.
 21. Vu D, Li Z, Zhang H, Wang W, Wang Z, Xu X, et al. Adsorption of Cu(II) from aqueous solution by anatase mesoporous TiO₂ nanofibers prepared via electrospinning. *J Colloid Interface Sci*. 2012;367(1):429-435.
 22. Le AT, Pung S, Sreekantan S, Matsuda A, Huynh DP. Mechanisms of removal of heavy metal ions by ZnO particles. *Heliyon*. 2019;5(4).
 23. Farghali AA, Bahgat M, Allah AE, Khedr MH. Adsorption of Pb(II) ions from aqueous solutions using copper oxide nanostructures. *Beni-Suef Univ J Basic Appl Sci*. 2013;2(2):61-71.
 24. Elboughdiri N. The use of natural zeolite to remove heavy metals Cu(II), Pb(II) and Cd(II) from industrial wastewater. *Cogent Eng*. 2020;7:1782623.
 25. Aeenjan F, Javanbakht V. Methylene blue removal from aqueous solution by magnetic clinoptilolite/chitosan/EDTA nanocomposite. *Res Chem Intermed*. 2018;44(2):1-25.
 26. Adnan A, Razak A, Shakor ZM, Rohani S. Optimizing Biebrich Scarlet removal from water by magnetic zeolite 13X using response surface method. *J Environ Chem Eng*. 2018;6(5):6175-6183.
 27. Moosavi S, Li RYM, Lai CW, Yusof Y, Gan S, Akbarzadeh O, et al. Methylene blue dye photocatalytic degradation over synthesised Fe₃O₄/AC/TiO₂ nano-catalyst: degradation and reusability studies. *Nanomaterials*. 2020;10:2360.
 28. Supelano GI, Gómez Cuaspud JA, Moreno-Aldana LC, Ortiz C, Trujillo CA, Palacio CA, et al. Synthesis of magnetic zeolites from recycled fly ash for adsorption of methylene blue. *Fuel*. 2019;263:116800.
 29. Salari N, Tehrani RMA, Motamedi M. Zeolite modification with cellulose nanofiber/magnetic nanoparticles for the elimination of reactive red 198. *Int J Biol Macromol*. 2021;176:342-351.
 30. Cheng R, Ou S, Xiang B, Li Y, Liao Q. Equilibrium and molecular mechanism of anionic dyes adsorption onto copper(II) complex of dithiocarbamate modified starch. *Langmuir*. 2009;26(2):752.
 31. Duan H, Hu X, Sun Z. Magnetic zeolite imidazole framework material-8 as an effective and recyclable adsorbent for removal of ceftazidime from aqueous solution. *J Hazard Mater*. 2019;384:121406.
 32. Mohammadi L, Rahdar A, Khaksefidi R, Ghamkhari A, Fytianos G, Kyzas GZ. Polystyrene magnetic nanocomposites as antibiotic adsorbents. *Polymers*. 2020;12:1313.
 33. Zhao J, Yang X, Liang G, Wang Z, Li S, Wang Z, et al. Effective removal of two fluoroquinolone antibiotics by PEG-4000 stabilized nanoscale zero-valent iron supported onto zeolite (PZ-NZVI). *Sci Total Environ*. 2020;710:136289.
 34. Lamba R, Umar A, Mehta SK, Anderson WA, Kansa SK. Visible-light-driven photocatalytic properties of self-assembled cauliflower-like AgCl/ZnO hierarchical nanostructures. *J Mol Catal A Chem*. 2015;408:189-201.
 35. Hernando MD, Mezcuca M, Fernandez-Alba AR, Barceló D. Environmental risk

- assessment of pharmaceutical residues in wastewater effluents, surface waters and sediments. *Talanta*. 2006;69:334-342.
36. Yoon Y, Westerhoff P, Snyder SA, Wert EC, Yoon J. Removal of endocrine disrupting compounds and pharmaceuticals by nanofiltration and ultrafiltration membranes. *Desalination*. 2007;202(1-3):16-23.
 37. Hollender J, Zimmermann SG, Koepke S, Krauss M, Mcardell CS, Ort C, et al. Elimination of organic micropollutants in a municipal wastewater treatment plant upgraded with a full-scale post ozonation followed by sand filtration. *Environ Sci Technol*. 2009;43:7862-7869.
 38. Yu Z, Peldszus S, Huck PM. Adsorption characteristics of selected pharmaceuticals and an endocrine disrupting compound—naproxen, carbamazepine and nonylphenol—on activated carbon. *Water Res*. 2008;42(12):2873-2882.
 39. Pan B, Qiu H, Pan B, Nie G, Xiao L, Lv L, et al. Highly efficient removal of heavy metals by polymer-supported nanosized hydrated Fe(III) oxides: behavior and XPS study. *Water Res*. 2010;44(3):815-824.
 40. Attia TMS, Hu XL, Yin DQ. Synthesised magnetic nanoparticles coated zeolite (MNCZ) for the removal of arsenic (As) from aqueous solution. *J Exp Nanosci*. 2014;9(6):551-560.
 41. Mohseni-Bandpi A, Al-Musawi TJ, Ghahramani E, Zarrabi M, Mohebi S, Vahed SA. Improvement of zeolite adsorption capacity for cephalixin by coating with magnetic Fe₃O₄ nanoparticles. *J Mol Liq*. 2016;218:615-624.
 42. Pizarro C, Rubio MA, Escudéy M, Albornoz MF, Munoz D, Denardin J, et al. Nanomagnetite-zeolite composites in the removal of arsenate from aqueous systems. *J Braz Chem Soc*. 2015;26(9):1887-1896.
 43. Zhou S, Li Z, Lv X, Hua B, Jia Q. Preconcentration of synthetic phenolic antioxidants by using magnetic zeolites derived with carboxylatocalix[4]arenes combined with high-performance liquid chromatography. *R Soc Chem*. 2015;140:5944.