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Investigating the adsorption method using polymer nanocomposites as adsorbent to remove organic pollutants: A review

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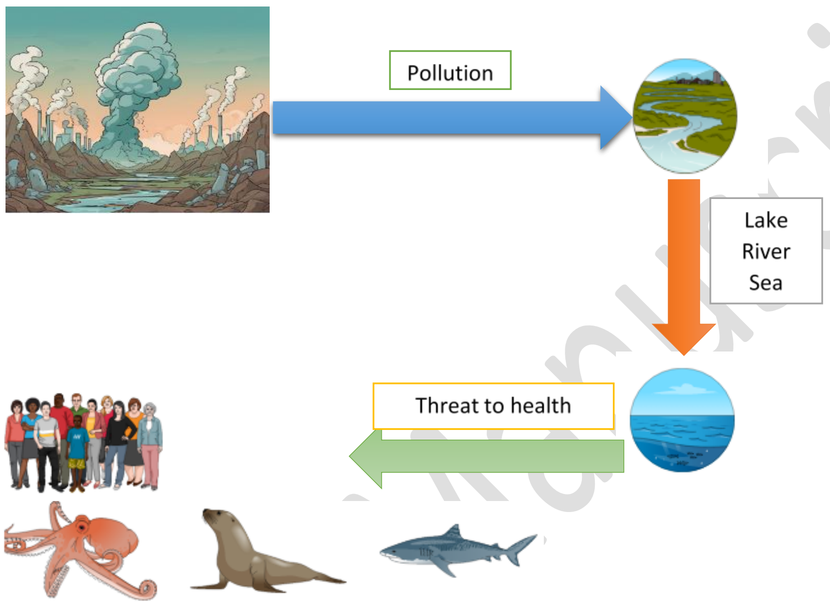
GRAPHICAL ABSTRAC



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ABSTRACT

It is becoming increasingly evident that numerous nations are teetering on the edge of a crisis induced by environmental issues, posing threats to the well-being of both humans and animals. Diverse factors characterized by vivid hues, like air pollution and fluctuations in water quality, contribute to a multitude of issues and can adversely impact the environment at large. Given the current heightened demand for freshwater reserves, there exists a more urgent necessity to devise pragmatic approaches for treating wastewater. One prospective technique entails the utilization of polymer nanocomposites to avert impurities such as heavy oils, cosmetics, and oil-based paints. These adjuncts leverage state-of-the-art nanotechnologies, such as carbon nanotubes and activated carbon, showcasing significant efficacy in refining water resources. Concurrently, striking a balance between financial viability and environmental benevolence. Moreover, the employment of adsorption methodologies proves to be highly efficacious in decontaminating tainted water reservoirs by eradicating organic pollutants, employing an array of substances as adsorbents for this purpose. Exemplars of thriving adsorbents include dendritic polymers MXenes, which manifest distinctive characteristics like heightened surface area and porosity, coupled with enhanced reusability and structural integrity when amalgamated with polysaccharides. Generally, the application of polymer nanocomposites as adsorbents for organic contaminants holds promising potential in innovating novel, cost-effective techniques for purifying water and shielding against chemical impurities.

1. Introduction

In a terrestrial setting, water plays a crucial role as a vital resource for maintaining the integrity of living organisms (Karmakar *et al.*, 2024). However, the adsorption of water quality resulting from anthropogenic activities poses considerable threats to environmental well-being. Consequently, removing harmful pollutants from the water supply has become a pressing global priority (Kulwant *et al.*, 2024). Moreover,

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ensuring unrestricted access to potable and cost-effective drinking water constitutes a basic humanitarian goal for the century (Bazaanah, and Mothapo, 2023). Clean water is an important source for the life and actuality of organisms (Jaishankar *et al.*, 2014). Despite the vacuity of water in numerous areas of the world, especially big metropolises, it's limited due to high population and rapid-fire industrialization. In this field, scientists have done a lot of exploration and the results showed that further than 700 inorganicmicro-pollutants(chromium, mercury, cadmium, lead, arsenic) and carcinogenic and largely poisonous organic (medicines, phenols, plasticizers, polybrominated diphenyl ethers), polychlorinated biphenyls, polynuclear sweet hydrocarbons). with different styles including face immersion (Jonathan *et al., 2008;* Khulbe and Matsuura, 2018*;* Siddeeg*,* Tahoon and Ben Rebah, 2019), electrolysis (Sahmoune, 2019), electrodialysis (Chebotarevaa, Remeza, and Bashtana, 2020), ionexchange (Al-Amshawee *et al*. 2020) and rear osmosis (Liu *et al*., 2020), can not be used in developing countries. Coagulation (Couto *et al.,* 2020), and flocculation styles and chemical (Skaf *et al.,* 2020), sanctification make them perform new sanctification and increase the cost of sanctification. checks showed that face immersion is substantially used in developing countries due to its lower cost and high effectiveness. By opting for a suitable adsorbent for wastewater treatment with different parameters such as immersion capacity, contact time, original attention, adsorbent cure, and result pH, the quantum of adulterants in water can be checked and controlled. The most essential adsorbents used for wastewater treatment include polymer resins Alshareef *et al*., 2020; Verma, and Balomajumder, (2020), biomass (Verma, and Balomajumder, 2020), agrarian waste (Coelho, *et al.,* 2020; Joseph *et al*., 2021, Silica Joseph, *et al*., 2021), color minerals, modified colorings (He *et al.*, 2020), zeolites (Thiebault, 2020), and actuated carbon (Chen *et al.,* 2020). To achieve this goal, novel materials capable of efficiently filtering out impurities at the same time, being economical, durable, and easy to disperse must be developed (Nam *et al.,* 2014). Nanotechnology holds significant promise in addressing these challenges, offering materials with exceptional separation efficacy, cost-effectiveness, and adaptability (Osman *et al.,* 2023). By exploiting the unique properties of nanoparticles, we can create highly porous and mechanically robust materials tailored for efficient water purification. However, the aggregation of nanoparticles hinders their practical application (Maroufi and Hajilary, 2023). In an encouraging turn of events, the incorporation of nanoparticles within composite structures termed nanocomposites has successfully alleviated the limitations encountered when utilizing carbon-based materials alone (Abbasi *et al.,* 2023). By capitalizing on the synergistic effects between these tiny particles, nanocomposites have demonstrated enhanced performance and durability, positioning them as promising candidates for resolving the pressing need for advanced water purification systems. Through a comprehensive analysis of diverse nanocomposites, their fabrication techniques, and their unique properties, this review provides insightful knowledge regarding their potential to address the current challenge in water treatment technology (Madhura *et al.,* 2019). The purpose of this study concerns the surface adsorption method investigated with polymers so that by removing organic impurities, we can see their effect on the environment. Different nanocarbons are used as adsorbents for other adsorption processes due to their good performance (Pan *et al*., 2019; Agboola *et al.,* 2019). Polymer nanocomposite adsorbents have recently been seen as a potential means of removing various pollutants from wastewater due to their strong mechanical strength and high stability. In general, the adsorption of desired polymeric materials depends to a large extent on the physicochemical structure of an adsorbent material (Mubarak, *et al*., 2024). Fig.1 shows that removing pollutants has several parts, each with an essential role in removing pollutants, including physical; chemical, physicochemical, and biological methods. Using these methods, it is possible to check and complete removing pollutants correctly and without errors (Sheikh, and Behdinan, 2023). Fig. 2 shows the general goal of removing organic pollutants in wastewater treatment, with the help of these methods, we can have good and trouble-free treatment. Table 1 concerns the advantages and disadvantages of other methods of wastewater treatment, which can check the advantages and disadvantages and choose the best material for the wastewater treatment, and test procedures can be done well.

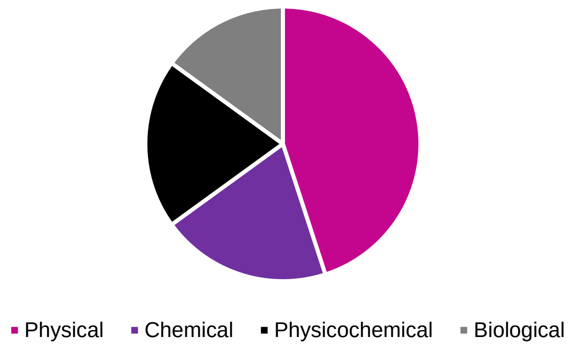


Fig. 1. The role of wastewater treatment.

2. Investigation of nanocomposites for environmental applications

Polymers have another type of fiber bound as an organic polymer matrix that divides into two parts strengthened plastics and progress composites. They have a lot of features that include mechanical properties, strength, and stiffness (Agboola *et al.,* 2021). They have a lot of advantages, such as lightweight and high stiffness. Therefore, they have two phases the matrix and the reinforcing (Mubarak *et al*., 2024). However, nanotechnology prefers the utilization of an atomic or molecular scale that affects nanoscale and structures, which can be in range from 1 to 100 nm (Sheikh and Behdinan, 2023; Safarkhani *et al*., 2024). Physical and chemical properties can search for the size material, surface area, volume, and the high interfacial reactivity ratio that can help to solve the problem (Kangishwar, *et al*., 2023). The synthesis has role importance in nanocomposite that shows improving barrier properties, flame resistance, optoelectronic properties, cosmetic applications, bactericides, and incredible water pollution removal (Zhao *et al*., 2023).

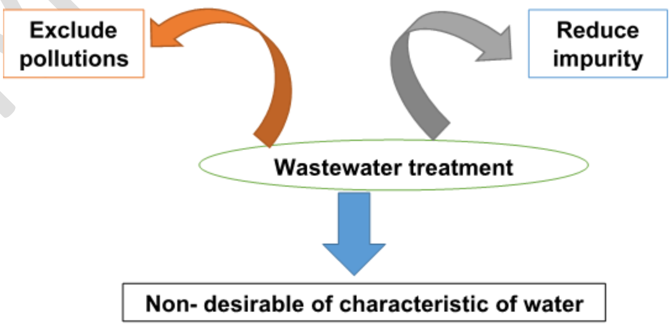


Fig. 2. The aim of wastewater treatment.

Their phase shows that dimensions in the nano range (10–100 nm) can affect the structure polymer and be used for additional parts that help to advance the nanocomposites (Madhura *et al.,* 2019 ;Pan *et al*., 2019; Agboola, *et al.,* 2019 ;Mubarak, *et al*., 2024 ;Sheikh, and Behdinan, 2023; Rahman *et al*., 2024). Dispersed matrix and phase materials can focus on current research including Polymer-based nanocomposites (PNCs) are vital in film-forming ability, dimensional variability, and activated functionalities (Zare et *al*., 2015). For example, nanoparticles have a very high surface-to-volume ratio and a high percentage of atoms/molecules with surfaces (Baer *et al.*, 2013; Jeevanandam *et al*., 2018). Carbon nanotubes have a ratio of length to diameter higher than 1000 with electrical conductivity along with mechanical properties (Schabel *et al*., 2007; Saifuddin, Raziah and Junizah, 2013). Nanofibers have physical and chemical properties, which show high size, surface, and resolution (Jian *et al.,* 2018). Nanosheets have wide dimensions and high surface area, which make them suitable for making reinforced polymer composites (Wang, *et al.*, 2012). Graphene quantum dots (GQDs) contain carbon, which absorbs graphene with a reduced band gap, whose physicochemical properties, play an essential role in graphene adsorption. Similarly, GQDs are used with other nanocomposites that provide fundamental applications in agriculture and the environment. In particular, GQD-based composites films, nanofibers, aerogels, and molecular polymers have suitable properties, that can address problems that include filtration membranes and adsorbents for pollutant removal, optical devices, and (bio) sensors for the detection of hazardous analytes including pesticides, heavy metals, antibiotics and food contaminants and new catalysts for removing contaminants (Mercante and Correa, 2021; James, Verma and Sharma, 2024; Facure *et al.*, 2021). Polymers encompass a distinct type of fiber confined within an organic polymer matrix that can be categorized into two segments: reinforced plastics and advanced composites (Agboola, *et al.*, 2021). These materials exhibit numerous characteristics, including mechanical attributes, strength, and rigidity (Agboola *et al.*, 2021).

Table 1. Advantages and disadvantages of other methods for water purification (Pan *et al*., 2019).

Number	Methods	Advantages	Disadvantages
1	Coagulation and Flocculation	Economically feasible	High sludge production
2	Ion-exchange	Effective	Not effective for disperse dyes
3	Advanced oxidation	Efficiency for recalcitrant dyes	by-products
4	Biodegradation	Economically attractive	Slow process, necessary to create an optimal favorable environment

They offer several benefits such as being lightweight and possessing high stiffness (Sheikh and Behdinan, 2023). Consequently, they consist of two main components: the matrix and the reinforcing phase (Kangishwar *et al*., 2023). Nevertheless, the realm of nanotechnology favors the application of atomic or molecular scale impacts on nanostructures, typically ranging from 1 to 100 nm (Zhao *et* al., 2023). The physical and chemical properties are examined concerning the size of the material, surface area, volume, and the high ratio of interfacial reactivity, which aids in problem-solving endeavors (Rahman *et al.*, 2024). The synthesis process plays a pivotal role in nanocomposites, showcasing enhancements in barrier properties, flame resistance, optoelectronic properties, cosmetic utilities, bactericidal functions, and remarkable water pollution mitigation. The phase characteristics indicate that nano-sized dimensions (10–100 nm) can influence the polymer structure and serve as supplementary components that propel the development of nanocomposites (Baer *et al.*, 2013).

The dispersed matrix and phase materials constitute a focal point in ongoing research, particularly in polymer-based nanocomposites (PNCs), essential for film-forming capabilities, dimensional variations, and activated functionalities (Jeevanandam *et al.,* 2018).

For instance, nanoparticles exhibit an exceptionally high surface-to-volume ratio and a significant proportion of atoms/molecules residing on their surfaces (Schabel *et al*., 2007).

Carbon nanotubes possess a length-to-diameter ratio exceeding 1000, accompanied by electrical conductivity and robust mechanical features (Saifuddin, Raziah, and Junizah, 2013). Nanofibers showcase distinct physical and chemical properties, highlighting substantial sizes, surface areas, and resolutions. Nanosheets boast extensive dimensions and elevated surface areas, rendering them suitable for fabricating reinforced polymer composites (Wang *et al.*, 2012).

Graphene quantum dots (GQDs) consist of carbon elements that assimilate graphene, resulting in a reduced band gap, thereby influencing graphene adsorption's physicochemical properties significantly (Facure *et al*., 2021). GQDs are integrated into various nanocomposites, offering essential applications in agriculture and environmental sectors. Specifically, GQD-based composite films, nanofibers, aerogels, and molecular polymers exhibit favorable properties capable of addressing challenges such as filtration membranes, adsorbents for pollutant elimination, optical tools, and (bio)sensors for detecting hazardous substances like pesticides, heavy metals, antibiotics, and food contaminants, as well as novel catalysts for contaminant removal (James, Verma and Sharma, 2024). Algae biomass serves as a fundamental resource for wastewater treatment, with diverse algae species playing crucial roles in this domain through metabolites and polymers. Carrageenan stands out as a vital polysaccharide with multifaceted applications in pharmaceuticals and diverse industries. Incorporating Carrageenan into bio-composites utilizing nanotechnology enhances film quality, food products, and medicinal items (Li *et al.*, 2024).These bio-nanocomposites exhibit improved stability, biodegradability, and biocompatibility, making them a viable option for drug delivery systems and wound care. Potato starch assumes a significant role in wastewater treatment across various industries due to its rich content of organic compounds (Li *et al.*, 2024). Reusing potato starch for wastewater treatment and discharge can yield clean, solvent-free water that is non-detrimental to the environment and living organisms (Safarkhani *et al.*, 2024; Li et al., 2024). conducted the synthesis of $Fe_3O_4@TiO_2$ nanoparticles through the application of ultrasonic chemistry and subsequently carried out an investigation on their properties for the purpose of eliminating organic contaminants present in potato wastewater. The outcomes of the study indicated that $TiO_2@Fe_3O_4$ nanocomposites exhibit the capability to eliminate organic pollutants found in potato starch, as demonstrated by UV/VIS spectrophotometry analysis. Under optimized conditions, the removal efficiency for COD and TOC was measured at 73.60% and 48.21%, respectively. Prior to the treatment of wastewater, the removal rates stood at 82.34% and 63.63%. The research delved into the mechanism of pollutant elimination facilitated by free radicals, emphasizing the crucial roles played by HO and H in the treatment of wastewater (Khan *et al.*, 2023; Zehui *et al.,* 2024). The utilization of nanocomposites has been recommended in the field of medicine, particularly in the treatment of diseases such as cancer. A notable example involves the application of nanocomposites comprising metal-organic frameworks with amine functionality, specifically (NH_2)-MIL-125 (Ti), which are conjugated with poly(aniline-co-para-phenylenediamine) and coated onto manganese ferrite nanoparticles. The results of this study revealed that these nanocomposites can deliver the chemotherapy drug doxorubicin (DOX) and the CRISPR plasmid (pCRISPR) to assist cancer cells in rectifying abnormalities in the body's cells. Further investigations highlighted that the surface modification with amine groups leads to enhanced cellular uptake and transfection efficiency. The key attributes of these nanocomposites for drug delivery applications are founded on the (NH_2)-MIL-125(Ti)/poly(aniline-co-para-phenylene diamine)/$MnFe_2O_4$ platform. Evaluations demonstrated a hemolysis rate of less than 1%, signifying the biocompatibility of these nanocomposites with cells. The introduction of amine modifications on the surface resulted in a 38.3% increase in cellular uptake and improved transfection rates. The use of such substrates in cellular environments has shown to enhance the therapeutic efficacy of drug delivery systems. In summary, this research study represents a significant advancement in the realm of gene delivery and expression for cancer therapy (Safarkhani *et al.,* 2024; Datta, 2024; *Sah et al., 2024*). The Fig. 3 is dedicated to elucidating the mechanism of nanocomposites, showcasing their pivotal and indispensable role in environmental applications leveraging these distinctive characteristics.

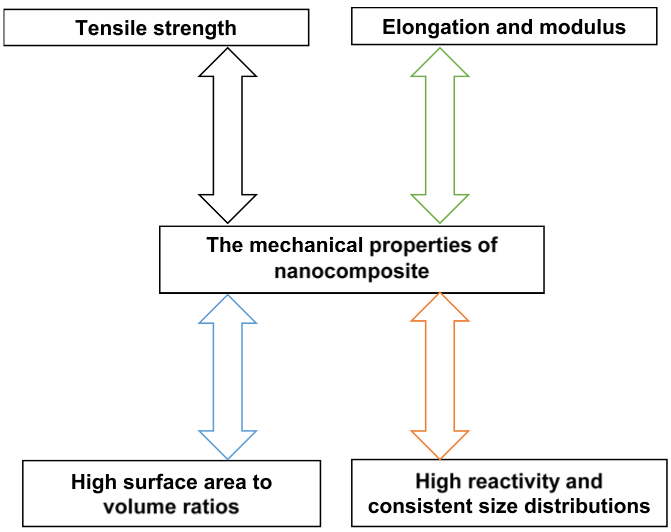


Fig. 3. The mechanical properties of nanocomposite.

2.2.Exploring techniques of organic pollutant in wastewater treatment

Organic pollutants, in general, are chemical compounds characterized by carbon-hydrogen bonds (Datta, 2024; Sah *et al.,* 2024). The abundance of organic compounds stems from carbon's ability to form chains with other carbon atoms (Sah *et al.,* 2024; Colorado *et al.*, 2024). The realm of organic chemistry delves into the properties, reactions, and syntheses associated with organic compounds (Colorado *et al.*, 2024; El Sayed *et al*., 2023). While certain carbon-containing compounds like carbonate anion and cyanide salts, along with specific exceptions such as carbon dioxide, are classified as inorganic primarily for historical reasons (Woldeamanuel *et al*., 2024), the classification of particular carbon-containing compounds remains a topic of contention among chemists, rendering the definition of organic compounds quite challenging (Ahmed *et al*., 2024). Despite constituting a minor fraction of the Earth's crust, organic compounds play a crucial role in sustaining life, underscoring their paramount importance (Šlachtová *et al.,* 2024), through the carbon cycle, living organisms convert inorganic carbon compounds into organic ones (Shaikh and Jagtap, 2023), initiating with the conversion of carbon dioxide and water (or alternative hydrogen sources) into simple sugars and other organic molecules (Ostadhassan and Hazra, 2023). Autotrophic organisms facilitate this conversion process using light (photosynthesis) or alternate energy sources (Börner and Zeidler, 2023).

Predominantly derived from petrochemicals consisting mainly of hydrocarbons, most organic compounds are artificially synthesized (Nayak *et al*., 2023; Santana and Shull, 2023).

These hydrocarbons, formed beneath the Earth's surface over extended geological time periods, result from the degradation of organic matter under high pressure and temperature conditions (Nayak *et al.*, 2023; Yu *et al.,* 2023). Illustrated in Fig. 4 are various organic compounds, each possessing distinctive and vital attributes essential in wastewater treatment.

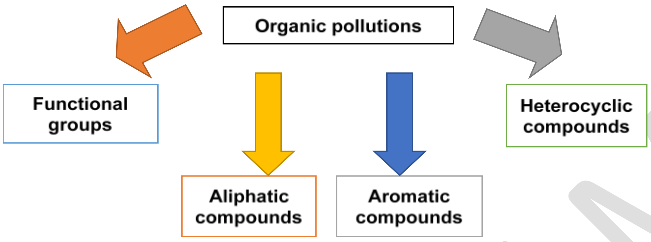


Fig. 4. Type of organic compounds.

2.3. Classify organic pollution

Other compounds are frequently categorized within the prominent groupings of organic chemistry such as organometallic chemistry, organophosphorus chemistry, organosilicon chemistry, and organosulfur chemistry (Inès *et al.*, 2023). Chemical transformations involving organic compounds are predominantly recognized as organic reactions, primarily associated with reactive functional groups. During these reactions, a key aspect involves a methodical examination of characteristics like the electron affinity of essential atoms, bond energies, and steric hindrance (Alfares, 2023). These characteristics play a crucial role in determining the relative stability of transient reactive intermediates that govern the specific reaction pathway. Addition, elimination, substitution, pericyclic, rearrangement, and redox reactions stand as pivotal processes in organic chemistry (Zhang *et al*., 2023). The realm of organic reactions is vast and virtually limitless. Nevertheless, in order to exemplify numerous common or practical reactions, it is customary to observe certain recurring patterns (Ngoc Van *et al.*, 2024). Each reaction follows a stepwise mechanism that elucidates its progression; however, it is not always feasible to accurately depict the stages solely based on a roster of reactants. The utilization of arrow-pushing techniques serves as a valuable tool in delineating the sequential pathway of each reaction mechanism (Rozzi *et al*., 2024). These techniques involve the use of curved arrows to trace the movement of electrons, as the starting materials evolve through various intermediates towards the final products C.

2.4. Synthetic organic chemistry

Synthetic organic chemistry is a branch of applied science because it is related to engineering, the "design, analysis, and, or creation of works for practical aims." Organic synthesis of new compounds is valuable because that determines the synthesis of a target molecule by selecting the best reaction from the best starting materials. Complex compounds may contain multiple reaction steps that sequentially produce the target molecule (Li *et al*., 2023*;* Jiang *et al.*, 2023; Mitschke, Vemulapalli and Dittmar, 2023). The synthesis continues due to the reactivity of active groups within the molecule. For example, a carbonyl compound is converted to an enolate and used as a nucleophile or electrophile, and their mixture is an aldol reaction (Rosendale *et al*., 2022; Jiang *et al.* 2023). To perform an actual synthesis, you need to perform a real laboratory synthesis. After the parts or proposed precursors undergo the same processing, usable and ultimately cost-effective starting materials are obtained. To achieve a synthesis, retrosynthesis is written in the opposite direction. A "synthetic tree" is designed so that each compound and precursor participates in another synthesis (Cervantes-Cuevas *et al.*, 2020).

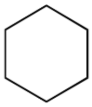
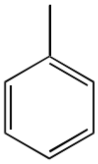
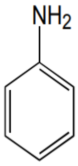
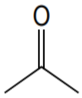
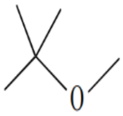
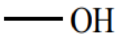
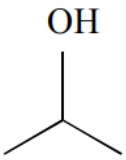
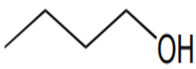
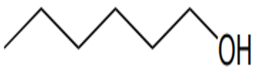
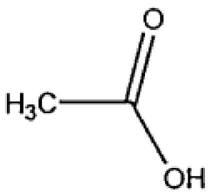
2.5.The role of variety methods using organic pollution

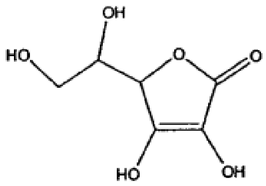
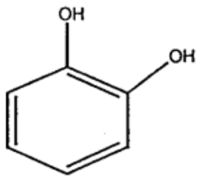
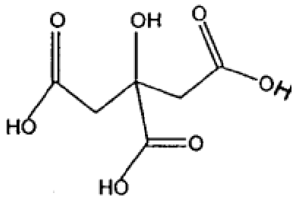
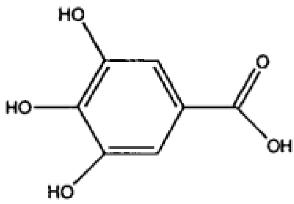
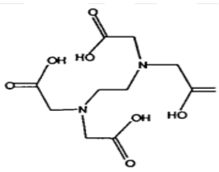
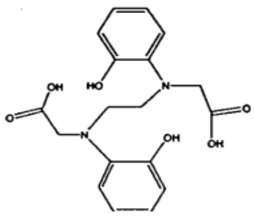
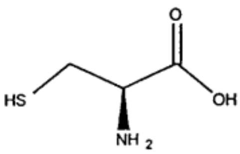
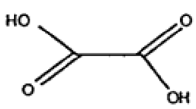
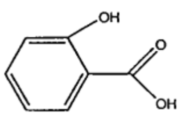
Active groups play a crucial role in molecular structures by influencing reactivity, limitations, and variations among molecules (Galvão *et al.*, 2023). Their impact extends to altering both the physical and chemical characteristics of organic compounds (Abbott *et al*., 2024). The classification of molecules becomes particularly significant in relation to active groups like alcohols, which involve the C-O-H group, and hydrophilic compounds capable of forming esters or converting into corresponding halides (Nandhini *et al*., 2023). Essential roles of active groups include atoms featuring C and H active groups heteroatoms (Shah *et al.,* 2024). Categorizing organic compounds proves useful for alcohols, carboxylic acids, amines, and other active groups, affecting the molecule's surroundings through electronegativity (Olatunji, 2024). As the active group or molecular addition increases, the resulting dipole moment becomes more intense or less intense based on the direction of the active group. Interactions within the surroundings and pH levels impact inter- and intra-molecularly through dipole distances and steric hindrance towards the active group (Shanmugapriya *et al.,* 2024). Varying bond strengths (single, double, triple) exhibit high electrophilicity and nucleophile strength, enabling active groups to engage in electrophilic attacks either inter- or intra-molecularly (Jezuita, Ejsmont and Szatylowicz, 2021). Groups possessing acidic properties like acyl or carbonyl groups can decrease vulnerability to attacks, with acyl chloride showing minimal susceptibility compared to carboxylic acids, thiols, malonates, alcohols, aldehydes, nitriles, esters, and amines (Sadi and Ouamerali, 2020). Nucleophiles or attackers play a crucial role by forming new structures with Aliphatic hydrocarbons, influencing bond formation and emphasizing the importance of active groups. Apart from these, compounds can exist in various forms such as straight-chain, branched-chain, or cyclic structures (Luo, 2015). Studies in the petroleum chemistry field have demonstrated how the degree of branching affects octane or cetane ratings *(Abu Rahim et al., 2023; Li et al., 2023; Ahmad et al. 2023).* Additionally, cycloaliphatic compounds yield cyclic derivatives comprising both unsaturated and saturated compounds, with the most stable rings typically containing 5 or 6 carbon atoms, although smaller or larger rings (macrocycles) also exist (Rubin *et al.*, 2023; Tyagi *et al.*, 2023).

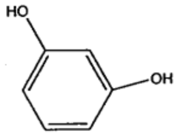
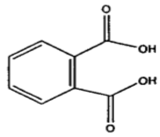
Among cycloalkanes, cyclopropane $(CH_2)_3$ stands out as the smallest group with three members. Saturated ring compounds exclusively contain single bonds, while aromatic rings exhibit alternating double bonds. Aromatic hydrocarbons, characterized by alternating double bonds, undergo sp^2 hybridization at each carbon atom within the ring, enhancing stability. Notably, benzene exemplifies this phenomenon and was the subject of the first proposal regarding delocalization or resonance as an explanation for its formation. For "normal" cyclic compounds, aromaticity is conferred by 4n+2 delocalized pi electrons (where n is an integer), while 4n pi electrons lead to anti-aromaticity, introducing a specific instability. The introduction of heteroatoms can further modify the properties of cyclic hydrocarbons (Abare, 2023; Mallick *et al.,* 2023). These atoms can be associated outside the ring (extracyclic) or inside the ring (intracyclic), in which case the ring is a heterocycle. Aromatic heterocycles include pyridine and furan at the same time, tetrahydrofuran and piperidine are alicyclic heterocycles. In general, sulfur, nitrogen, and oxygen are heteroatoms in heterocyclic molecules. Nitrogen is incredibly widely used in biochemical applications. Many products, such as aniline dyes and drugs, commonly contain heterocycles. In pharmacology, a significant class of organic pull options is small organic compounds, another name for small molecules, small biologically active non-polymeric organic compounds (Quiroz, Devier and Doloff, 2023; Mohapatra *et al.*, 2024; Toma *et al.*, 2024).

The molar mass of small molecules is 1000g/mol or less. In materials science, much research has been on fullerenes and carbon nanotubes, carbon compounds with tubular and spherical shapes (Quiroz, Devier and Doloff, 2023). They used a laser to vaporize rods of graphite in the presence of helium, creating molecules like ours (Boigenzahn *et al.,* 2023). The geodesic dome owned by this architect was created using the same design concept (Carey and Sundberg, 2002). Organic pull options that have bonds of carbon with nitrogen, oxygen, and halogens are generally classified into the same category (Fard *et al.*, 2017; Tavakoli *et al.*, 2023; Reddy Gajjala *et al.*, 2024; Li, Jin, and Chi, 2022). Table 2 shows the molecular structure of organic compounds with chemical formulas, each with specific properties and applications in wastewater treatment.

Table 2. Molecular structure of organic compounds..

Number of tests	Organic pollution	Structure	Chemical formula
1	Hexane		C_6H_{14}
2	Cyclohexane		C_6H_{12}
3	Toluene		$C_6H_5CH_3$
4	Aniline		$C_6H_5NH_2$
5	Acetone		$(CH_3)_2CO$
6	Methyl tert-butyl ether (MTBE)		$(CH_3)_3COCH_3$
7	Methanol		CH_3OH
8	2-propanol		C_3H_8O
9	1-butanol		$C_4H_{10}O$
10	1-hexanol		$C_6H_{14}O$
11	Acetic acid		CH_3COOH

12	Ascorbic acid		$C_6H_8O_6$
13	Catechol		$C_6H_6O_2$
14	Citric acid		$C_6H_8O_7$
15	1-cysteine		$C_3H_7NO_2S$
16	Ethylenediamine-N,N′-bis(2-hydroxyphenylacetic acid		$C_{18}H_{20}N_2O_6$
17	Ethylenediaminetetraacetic acid (EDTA)		$C_{10}H_{16}N_2O_8$
18	Gallic acid		$C_7H_6O_5$
19	Oxalic acid		$C_2H_2O_4$
20	Salicylic acid		HOC_6H_4COOH

21	Resorcinol		$C_6H_6O_2$
22	Phthalic acid		$C_8H_6O_4$

2.6. Resources of organic pollution

Wastewater contains myriad contaminants, among which the organic ones have a significant part. Sewage also includes other organic compounds, namely phenols, polycyclic aromatic hydrocarbons, aliphatic, heterocyclic compounds, herbicides, pesticides, and PCBs (Khan *et al.*, 2023;Jatoi *et al.*, 2024). Moreover, organic wastewater can also be caused by industries and agriculture along with people themselves, all of which can threaten water safety. Farm wastewater possibly comprises large amounts of herbicides or pesticides; the coke plant sewage can have other PAHs; chemical industries might emit various heterogeneous compounds, including PBDE and PCB; food industry discharge consists of complex organic contaminants having large amounts of BOD; municipal wastewater includes various organic pollutants, namely food, oil, and surfactants and dissolved organics. The existence of such organic contaminants in water may be detrimental to nature and negatively impact people's health. Based on their biological method, wastewater organic contaminants can be categorized into two classes: organic and persistent organic (Li *et al.*, 2023).The first group has a simple structure, moderate hydrophilicity, and is easily degraded in nature. For example, polysaccharides and methanol (organic pollutants) are broken down by bacteria, fungi, and algae. However, at high concentrations, some organic pollutants such as acetone and methanol can cause serious toxicity. However, persistent organic pollutants such as PAHs, PCBs, and DDT are metabolized or broken down slowly (Li *et al.*, 2023). Among other timeless chemicals, pesticides have been widely used for a long time. Compared with soluble organic pollutants, these chemicals have lower concentration and acute toxicity in wastewater; nonetheless, POPs are isolated in sediment and can be for several years. Water treatment is transported into the wastewater and then the food chain. Forever chemical shave lipid solubility and most preceding chemicals are teratogenic, neurotoxic, and carcinogenic. Such organic contaminants have become more scientifically attractive because they are toxic and persistent and can be transported long distances (Liu *et al*., 2024).

The following are the traditional toxic components in organic wastewater (Khan *et al.*, 2023). The organic substances existing in wastewater and sediment are generally water organic matter. The residues of plants, microorganisms, and animals are the sources of these matters, and they are categorized into two groups: non-humic and humus. The first group comprises other organic compounds related to organisms like carbohydrates, organic acids, and proteins at the same time, the second group mainly consists of specific organic compounds. Among the factors that can be affected by water organic matter, mention can be made physical and chemical features of water and the self-purification, adsorption, migration, and transformation in the water. Organic pollution with CH_2O and formaldehyde can primarily be obtained from the chemical industry, organic synthesis, synthetic fiber, wood processing, dyestuff, and the paint industry wastewater emissions. Highly reducible, formaldehyde can easily mix with varied substances (Smith, 2016; Liu *et al*., 2024; Liu *et al.,* 2024). Phenols from wastewater are obtained from oil refineries, insulation, paper, phenolic compounds, and coke plants.

Considered a human carcinogen, this chemical poses serious health risks even in small amounts. It may also reduce the ability of marine life to grow and reproduce. Having the chemical formula $C_6H_5NO_2$, nitrobenzene is an organic pollution generated abundantly as a precursor to aniline. This compound is sometimes utilized as a lab solvent, particularly regarding electrophilically reagents. Long exposure to nitrobenzene (said to be a potential carcinogen) might significantly damage the central nervous system, vision, and liver or kidney, and cause anemia and pneumonitis (Smith and March, 2007). The combination of biphenyls with 2 to 10 chlorine atoms results in PCBs, which have found wide applications as dielectric and coolant fluids; other PCBs, for instance, exist in the wastewater of capacitors, electric motors, and transformer factories.

These chemicals act as carcinogens and can accumulate in adipose tissue, cause diseases related to the brain, skin, and internal organs, and impact the nerve, reproductive, and immune systems. They have further been said to exhibit toxic and mutagenic influences through disrupting the body's hormones. As recalcitrant organic contaminants, PAHs include at most minor two benzene rings fused and arranged in linear, angular, or cluster forms. These pollutants can be found in oil, coal, and tar deposits at the same time, the PAHs in the aquatic system can result from sudden leakage, atmospheric deposition, and discharge of contaminated sediments. Because of their hydrophobic features, PAHs, particularly those having heavy molecules, typically have a low concentration in the water; however, due to their severe, mutagenicity, carcinogenicity, or toxicity, PAHs are one most harmful chemicals because they can accumulate in the nature and jeopardize the growth of living organisms. The sewage discharged from organophosphorus pesticide factories usually has a large number of pesticides, intermedia, and adsorption products; farm sewage may also include organophosphorus pesticides as it can be in nature for a long time. Water containing these pesticides can seriously pollute the environment. Some organophosphate pesticides are highly toxic to humans and animals. Although this pesticide is highly toxic, it is easily biodegradable. Wastewater from various industries and municipal wastewater are the central sources of petroleum hydrocarbons in water systems. Various combinations of petroleum hydrocarbons can be found in wastewater from oil production, oil production, transportation, and refining industries. These hydrocarbons are toxic to marine life and can further degrade water quality by creating an oily film layer that reduces oxygen exchange between water and air. This chemical herbicide is most often used in conservation tillage systems to prevent soil erosion. In dry farmland, it can suppress broadleaf weeds and weeds before and after emergence and increase the number of essential crops. Wastewater containing atrazine is mainly found in atrazine factories and congested agricultural fields (Clayden, Greeves and Warren, 2012; Apul *et al.,* 2013; Robati *et al.,* 2016; Saha *et al.*, 2017; Agboola *et al*., 2021; Li *et al.*, 2024; Raising Rathod *et al.*, 2024). Fig. 5 shows the role of organic compounds in wastewater treatment, each of which is necessary and essential based on the research and results obtained. Fig.6 shows the sources of organic compounds in natural and human processes.The most common organic pollutants include organic dyes, pesticides, and synthetic chemicals (Apul *et al.,* 2013; Robati *et al.,* 2016; Saha *et al.,* 2017).

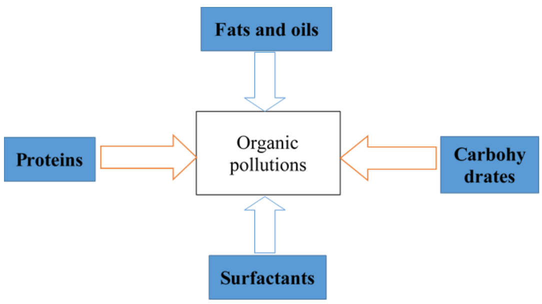


Fig. 5. The role of organic pollution.

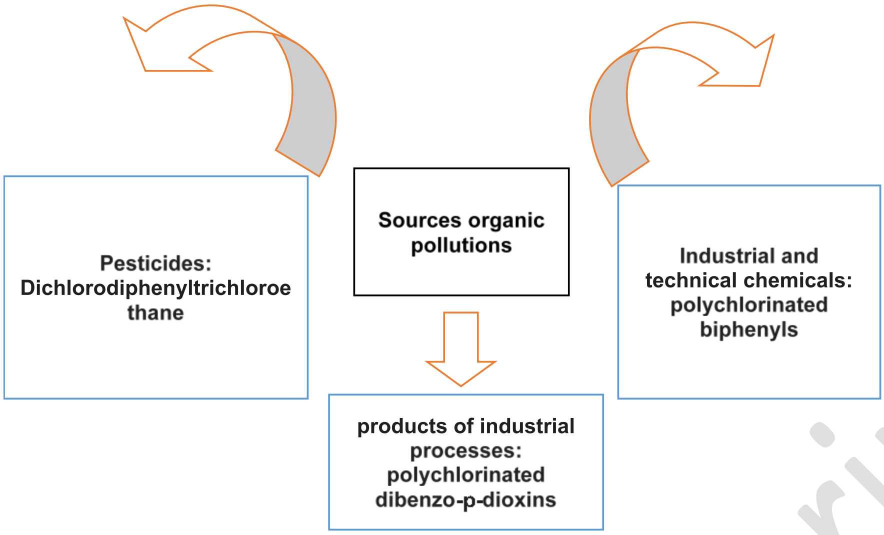


Fig. 6. Sources organic pollution.

2.7. Environmental dangers related to organic pollution

Large concentrations of hydrophilic organic contaminants such organic material and oil have the potential to consume considerable amounts of dissolved oxygen (Clayden, Greeves, and Warren, 2012). The demand for substantial oxygen quantities could have adverse effects on water quality and marine life (Agboola *et al.,* 2021). Nevertheless, microorganisms have the capability to efficiently degrade hydrophilic organic pollutants, mitigating their negative impact on the environment (Ju and Parales, 2010). Persistent Organic Pollutants (POPs), conversely, exhibit low water solubility, significant accumulation ability, and teratogenic, neurotoxic, and carcinogenic features (Sims and Overcash, 1983; Van den Berg *et al*. 1998; Pope, 1999; Raising Rathod *et al.,* 2024). For instance, the majority of previous organochlorine pesticides demonstrate teratogenic, neurotoxic, and carcinogenic characteristics . Benzofurans and dioxins are highly toxic substances that can persist for extended periods in both the human body and the environment. Subsequent to prolonged exposures that have been well-documented, various POPs like PCBs, DDT, dioxins, and especially chlorobenzene, have been detected in human body fat and serum (Aislabie and Lloydjones, 1995).

Improper usage of lindane (hexachlorocyclohexane), commonly employed in the treatment of body lice and as a broad-spectrum insecticide, can lead to significant elevation of tissue levels and result in severe consequences, including fatalities (Mathis, Mohr, and Zenobi, 2004; Raising Rathod *et al*, 2024).

The properties of the contaminant, as well as environmental factors such as pH, temperature, aging, and various other elements, can influence the toxicity of organic wastewater. Therefore, conducting further investigations to assess their long-term effects on the ecosystem is essential (Msaadi *et al*. 2019; Agboola *et al*., 2019; Raising Rathod *et al.*, 2024).

The Fig. 7 depicts the impact of organic compounds in the environment, highlighting their role in pollution and disease transmission across different sectors. These compounds enter the environment through sources like hospitals and industries, posing risks to the health of both animals and humans (Akhtar *et al.,* 2021).

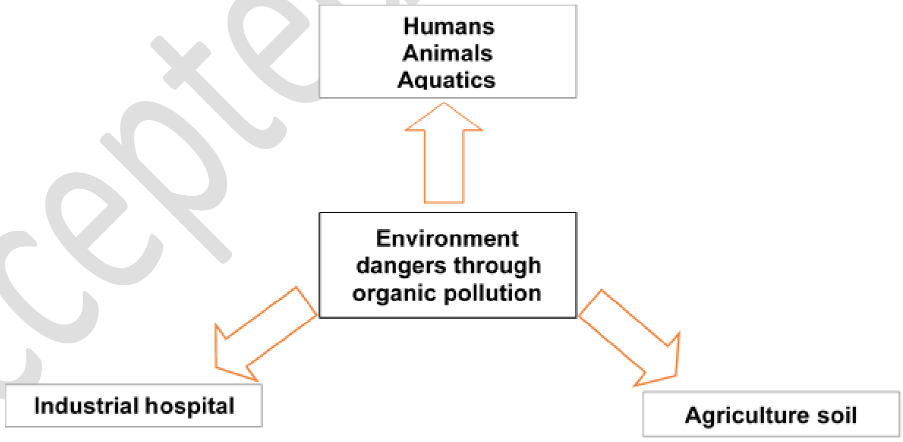


Fig. 7. The role of organic pollution in the Environment.

3.Polymer Nanocomposites

3.1.Polymer nanocomposites as an adsorbent using organic pollutions

Adsorption is a feasible method due to its economic advantages, and high efficacy. A variety of carbon-based materials have been used as adsorbents in a various variety of industries due to their outstanding performance under specific conditions (Pan *et al.*, 2019). However, there is a global urgent need to create highly specific adsorbents that can remove hazardous metals and organic pollutants in water treatment processes (Bhaumik, Setshedi, and Maity, 2013).Polymer nanocomposites have recently emerged as a suitable option for this purpose due to their impressive mechanical strength, excellent hydrodynamic properties, excellent stability, and tailored surface chemistry (Zhu *et al.,* 2015).

The adsorption capacity for target contaminants greatly depends on the microstructure, chemical composition, surface properties, and incorporated functional groups of the adsorbent material (Kotal and Bhowmick, 2015; Li *et al.,* 2023). Nanostructured adsorbents exhibit excellent adsorption efficiency and fast kinetic response due to their large surface area and easily accessible adsorption sites (Ben-Mansour *et al*., 2016). Careful study of adsorbent composition and adsorption rates has led to a thorough understanding of the impact of these variables on adsorption efficiency (Yong, Mata, and Rodrigues, 2001; Clayden, Greeves and Warren, 2012).

Additionally, their excellent adsorption properties, cost-effectiveness, and wide availability have led to significant interest in this field. Activated alumina, silica gel, various carbon materials (e.g. activated carbon and carbon fiber), zeolites, metal-organic frameworks, mesoporous silica (e.g. SBA and MCM), metal oxides (including calcium oxide and magnesia), layered double hydroxides (hydrotalcites), and , ion-exchange resin is an adsorbent with the ability to capture carbon dioxide (Songolzadeh, Ravanchi and Soleimani, 2012). However, physical adsorption is an adsorption process with a minimal capacity for ability to adsorb carbon dioxide at high temperatures (Rostami *et al.,* 2016).

In CCS processes, adsorption capacity and selectivity are contributing factors to adsorbent screening. (Rostami *et al.,* 2016). There is much evidence for the use of hydrotalcite, double salts, (Gholipour and Mofarahi, 2016), metal oxides including magnesia, calcium oxide, and alkali-metal compounds including lithium zirconate (Li_2ZrO_3), and lithium orthosilicate (Li_4SiO_4) (Mofarahi and Gholipour, 2014).

Carbon dioxide (an acidic gas) is adsorbed to the basic sites associated with alkali-metal oxides (including Na_2O and K_2O) and alkali-earth-metal oxides (e.g. calcium oxide (CaO) and magnesium oxide (MgO) or low carbon metal oxides (including alumina) (Mathis, Mohr and Zenobi, 2004). Chemical adsorbents may sometimes be used in pre-and post-combustion capture processes. (Helwani *et al*., 2012; Harada *et al.,* 2015).

The reaction between the adsorbent and the gas is aimed at producing metal carbonates by the chemisorption of carbon dioxide (Lee *et al.*, 2012)

The carbon dioxide produced during regeneration (reverse reaction) of is collected for further storage (Karbalaei Mohammad, Ghaemi and Tahvildari, 2019).

Chemical adsorbents reversibly adsorb carbon dioxide, and chemical treatment improves these properties (Karbalaei Mohammad,Ghaemi and Tahvildari, 2019). Alumina contains alkali-metal carbonates (including potassium carbonate (K_2CO_3),sodium carbonate (Na_2CO_3),lithium carbonate (Li_2CO_3) and alkaline-metal oxides (i.e. potassium oxide (K_2O), sodium oxide (Na_2O), and lithium oxide (Li_2O) (Karbalaei Mohammad, Ghaemi and Tahvildari, 2019). It is said to have been chemically modified, including (Li_2O) which improves the reversible adsorption capacity of carbon dioxide (Ju and Parales, 2010; Karbalaei Mohammad, Ghaemi and Tahvildari, 2019). Regarding carbon dioxide adsorption at high temperatures, layered double hydroxides (LDHs) such as hydrotalcite can also be considered as good adsorbents (Yong, Mata and Rodrigues, 2001).

The carbon dioxide capacity of LDH can be increased by changing the content and anion type and making chemical adjustments (Yong, Mata and Rodrigues, 2001).

Additionally,physical adsorbents can be used for carbon dioxide adsorption at temperatures up to 250°C (Yong, Mata and Rodrigues, 2001).

Research is underway on zeolites, carbon fiber composite molecular sieves, and carbon materials that have chemical devices that adsorb carbon dioxide at appropriate temperatures (Song and Lee,1998). Schematic diagrams of suitable adsorbents for CCS at different temperature ranges are mentioned by (Singh *et al.,* 2009).

Physsorption is reversible, which is its main advantage. The use of physical adsorbents allows for a controlled balance between carbon dioxide capacity and selectivity and the energy required for adsorbent regeneration (Burchell *et al.,* 1997).

MOFs, mesoporous silica, zeolites, activated carbon, carbon nanotubes, silica gel, and carbon are common physical adsorbents for carbon dioxide (Park *et al*., 2019).

These characteristics result in selectivity for adsorbing carbon dioxide from gaseous streams containing methane and nitrogen (Singh *et al.,* 2009),

However, the hydrophilicity of zeolites limits their ability to adsorb carbon dioxide. Some research has shown that activated carbon/zeolite composites are effective in adsorbing and separating carbon dioxide from nitrogen (Feng, An and Tan, 2007; Duis and Coors, 2016).

Metal-organic frameworks (MOFs) and mesoporous silica compounds possess a large surface area and pore volume, as well as adjustable pore diameters and mechanical stability (Crisafully *et al.,* 2008).

MOFs exhibit an exceptional capacity for carbon adsorption, whereas mesoporous silica demonstrates no discernible capacity for atmospheric carbon dioxide adsorption (Bury, Boyle and Cooper, 2011).

MOFs feature two or three-dimensional crystal structures, resulting in porous architectures quite similar to zeolites in terms of active properties (Pearson *et al.,* 1994).

Carbon dioxide adsorbents were investigated to identify potential adsorbents for zero-emission power generation (Takeuchi *et al.,* 2015). Additionally, chemical and physical adsorbents were examined for carbon dioxide separation and storage adsorption. CCS methods employing physical adsorbents consume less energy compared to those using chemical adsorbents (Saleh, Sarı and Tuzen, 2017). This advantage stems from the absence of new chemical interactions between the adsorbent and CO_2 (Sparks, 2003; Duis, Junker and Coors, 2021). Fig. 8 illustrates the natural polymers required for wastewater treatment, which are already utilized in various industries due to their non-toxicity.

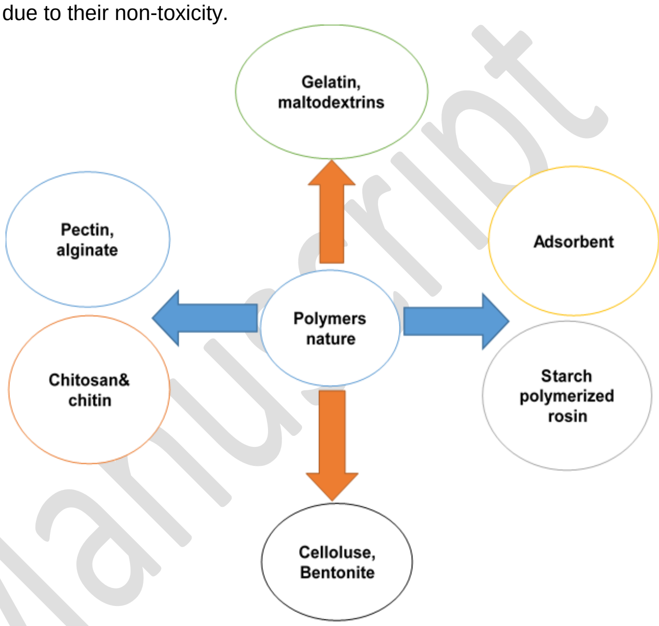


Fig. 8. Type of polymers nature as an adsorbent.

Biological systems synthesize three primary polymer types: nucleic acids, proteins, and polysaccharides. These are the fundamental macromolecules constituting any organism or biosystem, as they support metabolic and structural functions, as well as energy storage, genetic information transfer, and the synthesis of analogous molecules, enzymes, and complexes shaped by their interactions (Bernhard *et al.,* 2008). Polyesters, polyisoprene (rubber), polyethers (lignin), and more complex polyaromatics (melanin, and suberin) represent additional polymer examples in biosystems. Utilizing natural polymers eliminates industrial steps by bypassing the need for industrial synthesis. Consequently, the purification process can be completed using a wide range of environmentally safe solvents.

Since several of these polymer sectors already contain residues from other industrial processes, they offer a significant advantage over the development of new materials, which may be required to address contemporary challenges while reducing costs and emissions. Polysaccharides are more abundant, inexpensive, and readily extractable than nucleic acids and proteins, making them ideal materials for developing rectification target systems. Fig. 9 illustrates synthetic polymers; each of these substances is employed in various industries, but due to cost and other factors, they are more commonly used than natural polymers. Synthetic polymers are units produced artificially in manufacturing plants to exploit their properties during use. They can be fossil-based or bio-based. Due to similar chemical characteristics, identical biodegradability is expected when an artificial chemical compound is manufactured from natural sources or fossil fuels. Synthetic polymers exhibit a wide range of structural possibilities. These can be carbohydrate polymers like polyolefins or polystyrene (PS), but they can also contain heteroatoms, such as polyvinyl chloride (PVC), polyesters like polyethylene terephthalate (PET), polyether, polyamides like Nylon 6, and so on. Plastic materials encompass a broad spectrum of densities (0.01 to 2.3 g/cm^3; (Van den Berg, M*., et al.,* (1998), although it is worth noting that the densities of plastic objects can be altered by additives and environmental factors like weathering and fouling. While the majority of polymers (e.g., plastics) are essentially immiscible in water, some water-soluble polymers exist, such as Polyethylene glycols [PEG], Poly(vinyl alcohol) [PVA] or Poly(vinyl pyrrolidone) [PVP], anionic homo- and copolymers of propenoic acid, and ion polyquaterniums [PQs] (Chechetko,Tolpeshta and Zavgorodnyaya, 2017; Crini *et al*., 2019; Yousef, Qiblawey and El-Naas, 2020). Finally, there are synthetic polymers on the market considered biodegradable, such as polyhydroxyalkanoates (PHAs), the most prevalent being polyhydroxybutyrate (PHB), polylactic acid (PLA), polycaprolactone (PCL), and butene succinate (PBS). PHAs are also biopolymers, albeit produced in industrial facilities (Bernhard *et al.,* 2008; Eubeler, Bernhard and Knepper, 2010; Van den Berg *et al*., 1998; Chechetko,Tolpeshta and Zavgorodnyaya, 2017; Crini *et al.,* 2019; Yousef, Qiblawey and El-Naas, 2020).

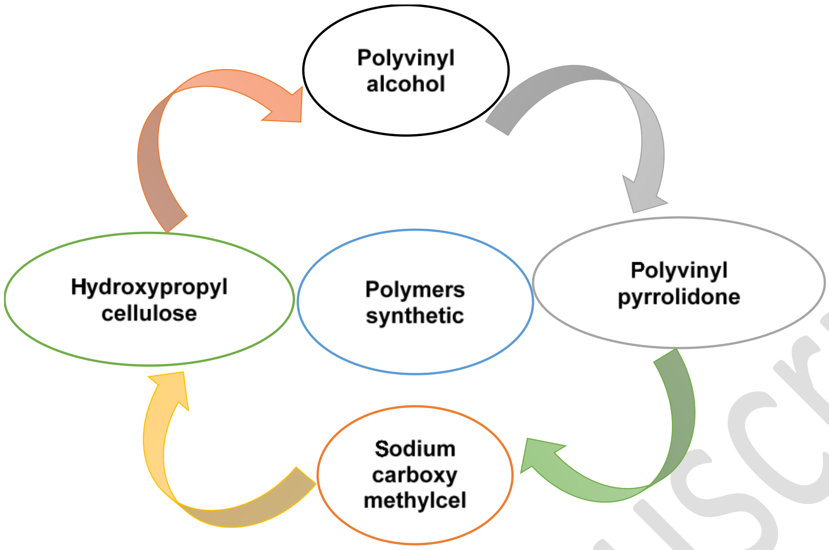


Fig. 9. Type of polymers synthetic as an adsorbent.

2.2.The investigation of organic pollution as an adsorbent

Water can be purified with various adsorbents. These adsorbents are often considered synthetic (non-natural adsorbents) or organic (natural adsorbents) .The following sections will discuss the most widely used adsorbents for treating contaminated water, primarily produced water. Adsorbents and biological sources in the earth's crust have been classified as organic materials (Ross and Shannon,1926; Khulbe and Matsuura, 2018). Fig. 10 offers the classification of adsorbents, with these methods, polymer adsorbents can be checked and good results can be obtained (Yousef, Qiblawey and El-Naas, 2020; George *et al.*, 2024).

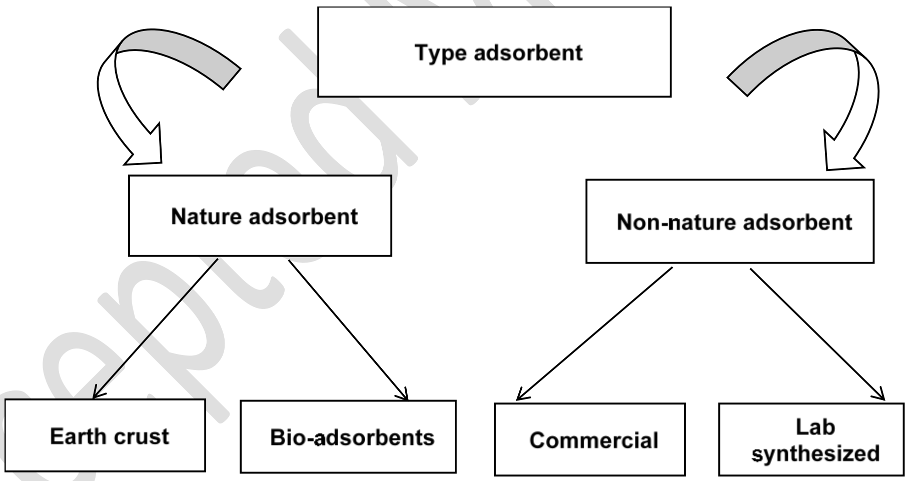


Fig. 10. Classification of adsorbents (Yousef, Qiblawey and El-Naas, 2020).

2.3.Comparison organic pollution as an adsorbent for wastewater treatment

Nowadays, many tests and research have been done in wastewater treatment using polymer nanocomposites as adsorbents, and the results showed that natural adsorbents are preferred over synthetic adsorbents because they are more economical (He and Zhu, 2017).

These adsorbents may exist in the earth's crust (Bury, Boyle and Cooper, 2011) biological resources such as wood and its derivatives; food waste, etc. in wastewater treatment. One of the studies on goethite (αFeO(OH)), which is naturally in the earth's crust (Wainipee *et al*., 2010) for removed arsenic (As) from water with and without oil coating. Studies show that goethite oil coating does not affect adsorption at the same time, reducing the adsorption capacity by half (Wolery and Jové Colón, 2017) In addition, during adsorption, the goethite surface was controlled by various variables. Graphite is also in the Earth's mantle (Pearson *et al.,* 1994). Takeuchi *et al.* (2015) studied exfoliated natural graphite as an adsorbent for removing oil from oil-water emulsions (Takeuchi *et al.*, 2015). They observed that the adsorbent can treat wastewater. Some researchers investigated graphene (a graphite layer) for removing antimony (III) metal from water. Their study shows that metals absorbed graphene with high efficiency (Saleh, Sarı and Tuzen, 2017; Sueyoshi et al., 2012) as goethite, clay minerals such as bentonite (Ross and Shannon, 1926), attapulgite (Sparks, 2003), Organochlorines (He and Zhu, 2017), and sepiolite exist in the earth's crust (Wolery and Jové Colón, 2017), which plays an essential and essential role in minerals, and wastewater treatment. Sepiolite has been used to remove oil from water, which has been used with two surfactants to adjust sepiolite adsorption, which includes stearyl trimethylammonium bromide and dimethyl octadecyl ammonium bromide (Okiel, El-Sayed and El-Kady, 2011). Investigations show that the adsorbents modified surfactants have adsorption capacity and align with the path (Zheng *et al.,* 2020), of physical endothermic adsorption. Attapulgite was used to remove oil from the wastewater treatment device, and then the potential was checked with activated carbon (Sueyoshi et al., 2012), and the results showed that the potential worth was lower and suitable for treatment(Gregg *et al.,* 2015; Emam, 2013; George, Ealias and Saravanakumar, 2024).

Another investigation is the presence of bentonite to remove oil from emulsion water (Okiel, El-Sayed and El-Kady, 2011; Ghaemi, Torab-Mostaedi and Ghannadi-Maragheh, 2011).

According to the study, the initial oil concentration was independent of the adsorption. Clay-modified bentonite has also been studied for oil recovery (Shahruddin *et al*., 2015). According to the findings, adsorption capacity plays an essential role in bentonite than activated carbon (Sabiani et al., 2023; Younker and Walsh, 2014; Younker and Walsh, 2015).

Clay minerals have a natural dolomite structure, which removes heavy metals, and barium plays an essential role in wastewater treatment (El-Naas, Al-Zuhair and Alhaija, 2010; Ghaemi, Torab-Mostaedi and Ghannadi-Maragheh, 2011). Dolomite powder has been used to remove strontium and barium from aqueous solutions. These chemicals are removed from solutions through exothermic adsorption and depend on the pH solution (Pan *et al*., 2019; Kunjirama *et al.,* 2017).

Dolomite has been considered as an adsorbent for removing strontium and barium (Kunjirama *et al.,* 2017; Youcef, Guergazi and Youcef, 2022).

Other studies show that clay adsorbents have been used for the pretreatment of various processes, including coagulation, membrane, and dissolved air flotation (Shahruddin *et al*., 2015; Al.Haddabi, Znad and Ahmed, 2015; Natesan and Rajappan, 2023), Bentonite as an adsorbent can increase the oil removal capacity (De Caprariis *et al.,* 2017; Okoro *et al.,* 2022).

Also, other parts showed that using adsorbents for wastewater treatment is appropriate in various fields and they adsorb organic pollutants (Kaveeshwar *et al.,* 2018). Olive, which has active carbon, can remove zinc, cadmium, copper, and lead pollutants from water (Sueyoshi *et al.,* 2012).

Based on their observations, pH is the most essential factor in olives, and they investigated palm oil for removing mercury and methylmercury from water (Sonil Nanda *et al.,* 2016; Elsherif, Alkherraz, and Ali, 2019). Using amine-containing ligands, which increase the adsorption capacity, can perform a good wastewater treatment that is stable in treatment and reuse (Sonil Nanda *et al.,* 2016; Araújo, *et al,* 2018).

Other investigations are for date palm, which is considered an adsorbent (Khan and Ali, 2018). Tests showed that dates were used at temperatures of 700℃, and 800 ℃ to remove oil (El-Naas, Sulaiman and Alhaija, 2010). The data obtained from wastewater treatment show that activated carbon has a better adsorption potential than other adsorbents based on temperature (Sonil Nanda *et al.,* 2016; El-Nafaty, Misau and Abdulsalam, 2013).

2.4.Investigating polymer nanocomposites to remove organic pollutants in wastewater treatment

Studies show that each nanocomposite has an essential role in the adsorption so they can have a good wastewater treatment with this method. For example, here are the other parts tests: The functionalization of rice husk can increase the adsorption potential and improve the stability reuse cycle, which is one advantage of these adsorbents in their availability and affordability. Biochar production using rice husk is very essential to remove nickel. prepared biochar at temperatures of 550 °C and 700 °C and showed a higher pollutant removal rate (Dey and Ray, 2020; Ibrahim *et al.,* 2016). Biochar extracted from wheat straw removed dissolved organic matter in wastewater treatment (Shakya and Agarwal, 2019; Shi, Hu and Ren, 2020). Treated the adsorbent with chitosan at 700 °C, which increased the number of micropores and thus improved the removal capacity. This straw biochar was proposed as an economic adsorbent for removing dissolved organic matter (Yuan *et al.*, 2010; Song *et al.,* 2014). Cadmium can contaminate wastewater treatment, so some scientists have used wood residues to absorb it. Rapeseed straw has been used to remove cadmium from the modified biochar method. through alkaline treatment with NaOH, MnO_4 saturation, or (iii) magnetic treatment with $FeCl_3$, where MnO_4 saturation gave better adsorption results due to increased micropore size and surface area.They used corn to remove cadmium in water (Shen *et al.,* 2017). At 400 °C, biochar was produced from corn, which showed an acceptable affinity for cadmium (Kudaibergenov et al., 2012). It should be noted that the same observations were made for lead. Sawdust biochar removed cadmium. Improved potential was observed after sawdust amendment with phosphoric acid (Shi, Hu and Ren, 2020; Yuan *et al.,* 2010). Similar results were obtained for copper (Li *et al.,* 2017).

Some studies have removed hydrocarbons changing the pore size of wood adsorbents.They used sawdust to investigate other pore sizes for absorbing naphthenic acid (Chi, Zuo and Liu, 2017). They used sawdust to produce activated carbon with other pore sizes. The difference in pore size depends on physical or chemical activation, with chemical activation showing tremendous removal capacity due to the more significant surface area adsorbent. Sugarcane with other mesh sizes was used for oil removal (Peng *et al.,* 2017). They observed improved oil removal reducing the particle size. Likewise, increasing particle size increased particle surface area and homogeneity, improving oil removal performance. Wood biochar showed the same pattern of adsorption of organic pollutants (Iranmanesh *et al.,* 2014). They produced biochars using 550°C, 750°C, and NaOH and 750°C. It is further improved NaOH treatment. Recently; food waste has been studied in wastewater treatment because fruits, wood fragments, and plants form the food chain (Grem *et al.,* 2013); Asenjo *et al.,* 2011). They used chitosan as food residue from shrimp shells to prepare polymer resins and remove oil. Studies have shown that reducing the flow rate improves the removal (Hosny *et al.,* 2016). Used chitosan as a coagulant and observed that adding chitosan improved oil adsorption and reduced pollutant removal costs. They examined raw eggshells and said that the oil was removed. Studies have shown that using raw materials is a more economical approach to wastewater treatment (Alqadami, A.A., et al., 2018). Activated carbon with a pecan shell was tested to absorb iron (II) using distilled water. As a result, a large amount of iron adsorbents were removed and the adsorption capacity improved with increasing temperature from 30°C to 70°C. They studied removing heavy metals (cadmium, cobalt, and lead) from water using nanocomposites derived from camel bone (Okiel, El-Sayed and El-Kady, 2011).

This approach is considered a new method for removing heavy metals through efficient removal (Yuan *et al*., 2010). Several studies have been done in the literature on unnatural adsorbents for wastewater treatment. The following are studies of adsorbents prepared in laboratory or industrial conditions (Asenjo *et al.,* 2011).

In this review, adsorbents synthesized in the laboratory refer to new adsorbents obtained through specific laboratory tests for wastewater treatment (Björklund and Li, 2017). Oil can be removed from diesel engines using carbon (waste) (Okiel, El-Sayed and El-Kady, 2011).

Investigations showed that such reserves are independent of the primary oil concentration. In addition, it was found that increasing carbon deposition increases absorbed oil. Deposited carbon is more cost-effective than activated carbon for oil removal (Yuan *et al.*, 2010) used porous carbons activated with potassium hydroxide (waste) to remove a mixture of polycyclic aromatic hydrocarbons (PAHs) (An *et al.,* 2016).

Porous carbon was obtained from petroleum coke, prepared during bitumen upgrading. They investigated the porous media of about five PAHs, namely pyrene, phenanthrene, fluoranthene, naphthalene, and fluorene, in water. Competitive adsorption in these PAHs was said to be unlikely and the adsorption potential was in the following order: naphthalene → fluorene → phenanthrene → pyrene, which their findings showed that the two-step method (with the first step being fast) controls PAHs (Jung *et al.,* 2019; Yuan *et al.*, 2010).

They used potassium hydroxide porous carbon to remove benzene and toluene from wastewater (Asenjo *et al.,* 2011). Carbon is derived from coal tar and has a microporous and mesoporous structure, which due to adsorption in mesopores, this dynamic has been used more than porous materials (Abdel-Shafy, Mansour and El-Toony, 2020). Activated carbon produced using sewage sludge and removing hydrophobic organic carbon has been used (Björklund and Li, 2017). Investigations showed that sewage sludge-activated carbon has the same potential as commercial-activated carbon, which indicates the economic use of waste. They used coal fly ash to absorb humic acid for wastewater treatment (Konggidinata *et al.,* 2017). An *et al.,* (2016) used microwaves and the effect of pH to modify coal ash with acids. The results showed that the adsorption potential is improved through adjustments and the determination of fly ash based on system pH. Jung *et al.* (2019) used millstone dust to remove lead and arsenic (Jung *et al.,* 2019). Small changes have been made in the stone powder using chitosan coating to see its effect on its ability to adsorb these metals. The results showed that successful adsorption with chitosan coating increases the adsorption potential of lead and decreases the adsorption potential for arsenic (Jang and Chung, 2018). New resin from gamma rays for oil removal was investigated by synthesis method (Laurent *et al.,* 2008).

To obtain resin, epoxy phenol resin, polyvinyl pyrrolidone, and Fe_3O_4 were mixed. After adsorption, microfiltration was performed to ultimately remove the oil (Fard *et al.*, 2017; Abdel-Shafy, Mansour and El-Toony, 2020).

Furthermore, thermodynamic studies of adsorbents showed that adsorption was endothermic, physical, and spontaneous (Yen *et al.,* 2017; Jang and Chung, 2018). They used a titanium-based adsorbent for lithium removal, which showed a high affinity for the studied adsorbent when used with a pH buffer.

Adsorbents based on nanotechnology are also considered fundamental components in laboratory-synthesized adsorbents (Franco, Nassar and Cortés, 2014; Khan, Saeed and Khan,2019). Recently, nanoparticles using other materials have been studied to remove oil from produced water (Cortés *et al.,* 2014) used silica-based nanoparticles (Franco, Nassar and Cortés, 2014).

The oil was removed by treating the wastewater and these nanoparticles were made using the vacuum residue from the oil and tested in fresh and saltwater (Fard,*et al.* 2016;Laurent *et al.,* 2008; Moura, *et al.,* 2011). The results showed that the adsorbents analyzed (with and without ventilation) ultimately removed the oil, but for other durations, which were said to be related to the type and performance of water. (Franco *et al.*, 2014). further studied alumina nanoparticles in removing oil adsorption (Albatrni *et al.*, 2019). In this research, they also used petroleum vacuum residue and observed the same performance. However, according to their research, alumina nanoparticles had significant selectivity for oil due to the polarity of silica nanoparticles (Younker and Walsh, 2014; Reddy, McDonald, and King, 2013).

Carbon nanotubes are synthesized in the laboratory for oil removal through iron oxide functionalization than carbon nanotubes Fard, *et al.* (2016). Carbon nanotubes modified with iron oxide showed better oil adsorption than nanotubes that did not complete well (Fard *et al.,* 2017; Yen *et al.,* 2017). Modified nanoparticles in organic clay (nano clay) were used by scientists to remove petroleum hydrocarbons from water (Franco, Nassar and Cortés, 2014; El-Naas, Al-Zuhair and Alhaija, 2010).

To modify the nano clay, sodium ions in the montmorillonite structure were replaced by hexadecyltrimethylammonium bromide (Fard *et al.,* 2016). Modified nano clay had almost higher adsorption potential than unmodified nano clay (Iranmanesh *et al.*, 2014; Moura *et al.,* 2011). MXene nanosheets are made of titanium (III) (II) carbide, and scientists have used them to remove organic pollutants using the adsorption method, including barium in wastewater treatment (Albatrni *et al.*, 2019; Fard *et al.,* 2017; Younker and Walsh, 2014; De Caprariis *et al.,* 2017) than other adsorbents, these nanosheets showed better adsorption potential and selectivity for barium in polymetallic solutions. Copper oxide nanoparticles were used to remove copper oxide nanoparticles from water (El-Naas, Al-Zuhair and Alhaija, 2010; Belbase *et al.*, 2013).

Investigations showed that these nanoparticles are more effective after disposal because the reaction surface can be used again after purification (El-Naas, Sulaiman and Alhaija, 2010; Yen *et al.,* 2017).

Treatment of copper oxide with dendrimer-modified magnetic nanoparticles removes heavy metals such as palladium, gold, and silver) (Rosenblum *et al.*, 2016; Ma *et al.*, 2020; Yen *et al.* 2017; Iranmanesh *et al.,* 2014).

Regarding wastewater treatment, research on mineral adsorbents, including commercial adsorbents, is also ongoing.
Scientists used zeolites to adsorb toluene and sodium (Na) cations. Based on natural coal seam wastewater treatment, sodium adsorption is inversely proportional to zeolite size (De Caprariis *et al.,* 2017; Belbase *et al.,* 2013; Ma *et al.,* 2020; Lahnsiner, 2021). To evaluate the effectiveness of zeolites, their adsorption was analyzed in situ. According to the data of this experiment, soil damage by Na ions was less in the treated soil (Yong, Mata and Rodrigues, 2001; Belbase *et al.,* 2013). Toluene was investigated based on column and batch experiments and showed better adsorption potential than zeolite because the former is stable during desorption. It should be noted that these scientists coated the zeolites with diphenyl-dichlorosilane (Regufe *et al.,* 2019; Belbase *et al.,* 2013). They used commercially modified mesoporous silica adsorbents to remove aromatics, including benzene, toluene, o-xylene, and p-xylene (BTX) (Moura *et al.,* 2011). According to their data, these compounds were adsorbed on the silica surface under the influence of van der Waals forces. In addition, organosilica has a characteristic hexagonal mesoporous structure and can operate even at 340 °C (Moura *et al.,* 2011). Wastewater treatment oil was removed using 4 other commercially synthesized resins (Ma *et al.,* 2020). The results showed that the commercial resin is independent of pH and has oil selectivity (Albatrni *et al.,* 2019). Furthermore, Amberlite XAD showed the fastest kinetics and Lewatit showed the highest adsorption potential (Albatrni *et al.,* 2019). Commercial activated carbon has been frequently mentioned in some studies, most of which used it as a source of adsorption capacity (Okiel, El-Sayed and El-Kady, 2011; Rosenblum *et al.,* 2016). Clay and commercial activated carbon were compared with organic clays, bentonite, and attapulgite. In the case of attapulgite, the activated carbon was more significant in surface area, leading to better oil adsorption potential (El-Naas, Alhaija and Sulaiman, 2017). Compared with organic clay, activated carbon could adsorb naphthalene and phenols well (Younker and Walsh, 2014). However, bentonite has a tremendous potential for oil removal, so it is more suitable than activated carbon (Cheng *et al.,* 2024; Emam, 2013; Iranmanesh *et al*., 2014; Cortés *et al.,* 2014) Another study compared commercial activated carbon and sawdust-based activated carbons, where it was observed that the latter has a tremendous potential to remove naphthenic acid (Iranmanesh *et al*., 2014). A further comparison was made between biochar and activated carbon, whose adsorption potential for organic compound removal was 2.5 times higher than that of biochar (Cortés *et al.,* 2014; De Caprariis *et al.,* 2017; Peng *et al.,*2017). In one study, adding a coagulant increased the adsorption potential of commercial activated carbon for removing hydrocarbons and polyethylene glycol in hydraulic fracturing (Ralte *et al.,* 2023; Rosenblum *et al.,* 2016). The adsorption of phenol was studied by scientists using activated carbon in packed beds and showed a significant dependence on feed concentration, flow rate, and amount of load by (El-Naas, Alhaija and Sulaiman, 2017). Langmuir method has been used for modeling and good results are obtained from this model and the correlation coefficient worth should be close to 1 (Bessekhouad, Robert and Weber, 2003; Tahir, Bhatti and Iqbal, 2016).

There are various technologies in treating wastewater in metal removal are divided into physical, chemical, and processes such as metal precipitation, immoderate filtration, biological systems, oxidation, solvent extraction electrolytic processes, ion exchange, membrane filtration, and adsorption. Physical and chemical treatment is a lot of expensive than biological treatment in removing metal but biological treatment lacks effectiveness and timely method (Moriarty, 2001; Hang *et al.,* 2002; Gubin *et al.,* 2005; Liu, Liang and Guo, 2005; Zhai *et al.,* 2006; Wigginton, Haus and Hochella Jr, 2007; Auffan *et al.,* 2009; Kalfa, Yalçınkaya and Türker, 2009; Macwan, Dave and Chaturvedi, 2011). Advantages and disadvantages of physical and chemical current treatment were simplified adsorbent in Figs.11 and 12 regarding the adsorption in wastewater treatment, which, supported experiments, and showed that lower worth plays a fundamental role. Tables 3 and 4 regarding the quantity of waste material removal capability and the way a lot of pollutants are reduced .

Table 3. Nature adsorbent capacity with variety materials.

1	Chitosan Microspheres	>90	**Hosny *et al.*, 2016**
2	Chitosan	52	**Liu *et al.*, 2019**
3	Pineapple Peelc	82.63	**Song *et al.*, 2014**
4	Corn Straw	99.24	**Peng *et al.*, 2017**

Table 4. Non- nature adsorbent capacity with variety materials.

1	Activated Carbon	92	**El-Naas, Alhaija and Sulaiman, 2017**
2	Deposited Carbon	97.5	**Okiel, El-Sayed and El-Kady, 2011**
3	Carbon Nanotubes	87	**Moura *et al.*, 2011**

4	Powder activted carbon	82.6	**Ma *et al.*, 2020**

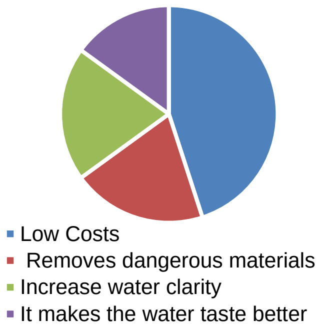


Fig. 11. Advantages of adsorption in water treatment.

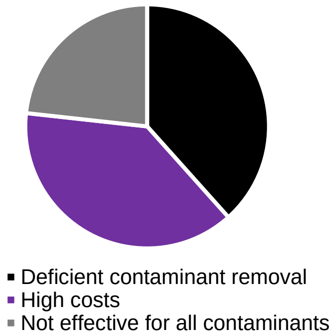


Fig. 12. Disadvantages of adsorption in water treatment.

2.5. Comparison nano adsorbent with other characterization

The new nano-adsorbents are essentially nanoparticles. The central stages of manufacturing nanoparticles are condensation inert gas, generating spark discharge, spray pyrolysis, pulsed laser ablation, laser pyrolysis, ion sputtering, photothermal synthesis, flame synthesis, and thermal synthesis plasma synthesis, low-temperature reactive, and flame spray pyrolysis (Handy *et al.,* 2008). Nanoparticles are primarily characterized using (XPS), (EDS), (XRD), (SEM), (TEM), and EXD methods. These techniques are used to create other first-generation adsorbents for use in other applications, such as electronics, mechanical, optical, and biomedical fields, water treatment, and environmental science (Bina, Amin, and Rashidi, 2012). The process is chosen based on the characteristics, size of the starting components, and the key functions of the new generation of adsorbents. The sol-gel process is widely utilized to produce new generation adsorbents such as maghemite, titanium oxide, cadmium sulfide, alumina-silica, nickel oxide, alumina, silica, and zinc sulfide. The methods for producing and characterizing these adsorbents are beyond the scope of this article. Still, those interested in this topic may turn to the many texts regarding nanotechnology (Zhao *et al.,* 2010). Researchers have recently focused on nanoscale solid materials and nanomaterials in general due to their unique properties. Small particles' chemical and physical properties alter as their size decreases, owing primarily to the increased fraction of surface atoms that occur in other conditions (such as the number of coordination and the local environment symmetry) when compared to bulk particles. Furthermore, decreasing particle size increases the surface energy portion (Oh *et al.,* 2007). Nanomaterials exhibit unique chemical and physical characteristics. For example, most atoms are reactive and have a good adsorption potential for different metal ions on the surface of nanomaterials (Nasrollahzadeh, Ehsani and Rostami-Vartouni, 2014). Because it is unsaturated, its surface atoms are susceptible to combining with ions from other elements due to static electricity. Nanomaterials thus have a remarkable ability to remove numerous contaminants, particularly polar chemical molecules and trace elements (Goyal, Bulasara and Barman, 2016). Materials moved down to the nanoscale can quickly exhibit various properties than those at the microscale (Shveikin, 2006; Mahmoodi and Saffar-Dastgerdi, 2019).

Two effects can explain this phenomenon, one of which is related to the surface, meaning the higher number of atoms on the surface in comparison to the inner atoms, the higher availability of free energy on the surface owing to the more significant surface area and more atoms, and the augmented rate of chemical reaction, which is primarily related to the increased surface area (Shveikin, 2006; Goldstein *et al.,* 2017; Panahdar *et al.,* 2021).

The second group of effects is associated with the volume, caused by a lower wavelength (more frequency and energy), a blue shift in atoms related to optical adsorption spectra, superparamagnetism occurring when the particle has a smaller size compared to the magnetic area in a substance, and the increase in the average energy spacing in a free-electron model because fewer atoms, which improves the catalytic features of nanoparticles (Shveikin, 2006; Goldstein *et al.,* 2017). Researchers carefully analyzed the size-dependent properties of various inorganic nanoparticles (NPs) and concluded that crucial particle size (about 30nm) represents a major change in particle features. Nanomaterials' key physical qualities are dictated by the type of nano-objects they include. These nanomaterials are divided into compact materials and nanodispersions, the former possessing nanostructured substances, specifically isotropic materials, in their macroscopic composition and comprising connected units of a nanometer size that repeat the structural elements (Bustamante, Fernández and Zamaro, 2014; Wang and Balandin, 2001).

Nanomaterials are classified primarily based on their role in adsorption, which is further determined by their inner surface characteristics and exterior functionalization (He *et al*., 2019; Wang and Balandin, 2001).

Nanoparticles can be metallic (e.g., gold NPs), metallic oxide (e.g., aluminum trioxide or titanium dioxide), nanostructured mixed oxides (e.g., binary iron-titanium mixed oxide particles), or magnetic (e.g., iron di and trioxide) (Vijayakumar *et al*., 2010).

Carbonaceous nanomaterials (CNMs) constitute another significant class according to sorbent features, such as carbon nanoparticles (CNPs), carbon nanosheets (CNSs), and carbon nanotubes (CNTs). Similarly, silicon nanomaterials (SiNMs) contain silicon nanoparticles (SiNPs), silicon nanosheets (SiNSs), and silicon nanotubes (SiNTs). Nano clays, nanofibers (NFs), polymer-based nanomaterials (PNMs), and xerogels and aerogels are among other nanomaterials utilized in adsorption processes (Xie *et al*., 2015). Nanoparticles (NPs) are used in a variety of fields, including electronics, chemistry, biology, material sciences, and medicine, with sizes ranging from 1−100nm. The physical, material, and chemical properties of nanoparticles are directly related to their interior structures, observable sizes, and outer surface structures (Loiola *et al,* 2012).

As a result, it is required to account for their design, synthesis, characterisation, and use in nanomaterials (Huang *et al.,* 2006; Loiola *et al.,* 2012).

Nanoparticle-assisted sample separation and preconcentration are important components of various analytical procedures (Loiola *et al.*, 2012).

In separation research, numerous investigations have been conducted on the capabilities of NPs, and significant progress has been made in chromatographic and electrophoretic systems involving some separation components and pre-concentration media. Coating interior surfaces in stable or dynamic mode, adding them to the buffer as a pseudo-stationary phase, and using them in partial or continuous filing applications (Loiola *et al.,* 2012).

Nanoparticles are quasi-zero-dimensional (0D) nano-objects with spherical shapes and equal characteristic linear dimensions (maximum 100nm). Some nanoparticles (NPs), also known as nanocrystallites, have visibly arranged atoms (or ions) (Loiola *et al.,* 2012; Gadipelli *et al.,* 2016).

Quantum dots, often known as artificial atoms, are nanoparticles having an evident discontinuity in their electronic energy level system; these nanoparticles primarily feature semiconductor-like properties. Previously used in chemical literature, the term "cluster" is now used to designate nanoparticles smaller than 1nm. As a result, the term "nanocluster" is misleading because each cluster is only nanometers in size. Aside from size, additional factors influence the characteristics of LF. (i) Surface chemistry (surface functionalization and surface charge), (ii) Aggregation state, form, and fractal dimension, (iii) Chemical and crystalline composition, and (iv) Solubility. There have been various review studies (e.g., researchers) on how nanoparticles react in aquatic environments (Sann *et al.*, 2018).

In terms of how the environment affects NP behavior, NPs can alter significantly in the liquid phase. Researchers are actively considering NPs as sorbents because they have superior intrinsic properties, including small particle size and chemical activity, than conventional materials, such as alumina and normal-scale titanium dioxide) (Hu *et al.,* 2011).

2.5.1.Investigating the characteristics of various nanocomposites

2.5.1.1. The role of FTIR to removal of pollution by using nanocomposite

Fig. 13 shows the FTIR spectrum of the produced nanocomposite. Testing revealed specific groups at 465, 470, 468, and 466 cm^{-1}. This graphical depiction specifically shows the bending vibration (Si,Al)-O bond for zeolite, sodalite zeolite nanoparticles (SZN) (0.5), SZN (1), and SZN(1.5). The peak at 666 cm^{-1} in synthesized nanomaterials is due to the symmetric expanding vibration of (Si,Al)-O. Similarly, the additional bands at 985, 983, 978, and 990 cm^{-1} are almost related with the internal swerved stretching vibration of (Si,Al)-O for zeolite, and SZN(0.5), SZN(1), and SZN (1.5) (Huo *et al.,* 2018). The presence of active groups and H_2O bonds was confirmed between the bands of 3545 and 3441 cm^{-1} for zeolite. This presence of water within the zeolite indicates that it was not subjected to drying (Li *et al.,* 2019).

The proportion of R-NH_2 groups to N-H vibrations is visible in the groups that appear within the graph at worth of 1490 and 1590 cm^{-1} in SZN(0.5), SZN(1), and SZN (1.5). Finally, the peak at 2935 cm^{-1} is associated with C-H stretching vibrations, while the same time, the symmetric stretching vibrations with values of 3434, 3440, and 3434 cm^{-1} result in H-C-H in SZN(0.5), SZN(1), and SZN(1.5) (He *et al*., 2014; Hurma, 2019). The study found no significant changes in the chemical reactions between γ-aminopropyltriethoxysilane (APTES) molecules and zeolite did not display conspicuous differences.

Fig. 14 shows the pure nanocomposite peak in the spectrum of 600-1350 cm^{-1} for the bending of the imidazole ring (Huang, X.C. *et al*. 2006; Gadipelli *et al.,* 2016; Sann *et al.,* 2018) the peak at 1580 cm^{-1} for the stretching vibration with the peaks at 2960 and 2930 cm^{-1} attributed to aliphatic CH bonds, which are related to the antisymmetric, and stretching vibrations of CH_3 and CH_2 of the imidazole ring (C=N) (Hu *et al*., 2011; Hu *et al.,* 2011; He *et al*., 2014; Huo *et al*., 2018; Li *et al*. 2019; Huo *et al.*, 2018; Li *et al.*, 2019; Oveisi, Mahmoodi and Asli, 2019). It shows the adsorption nanoparticles at peaks about 480cm^{-1},1592, and 3448 cm^{-1} are related to stretching vibrations, and the O-H bond that is related to absorbed water, the reaction of nanoparticle with oxygen, and peaks close 600-1500;1,580;2,960; 2,930; and 3135cm^{-1} in the synthesized nanocomposite related to the imidazole ring (Tian *et al.,* 2016; Hurma, 2019).

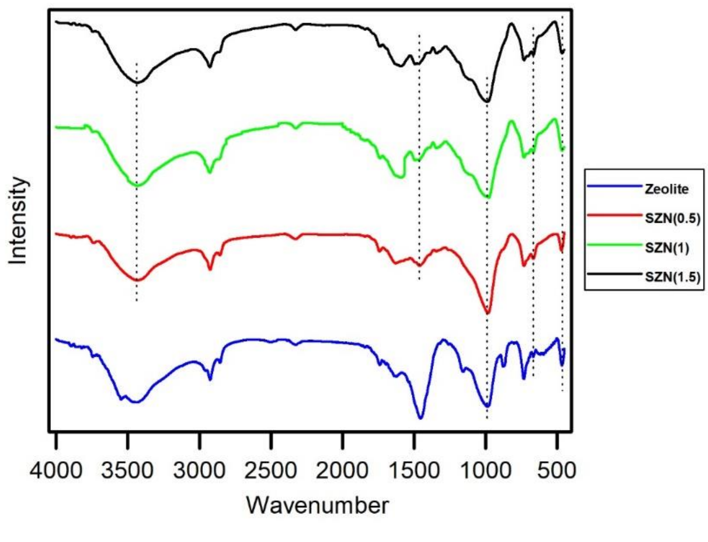


Fig. 13. FTIR spectrum of Zeolite, and SZN with different ratios (Mahmoodi and Saffar-Dastgerdi, 2019).

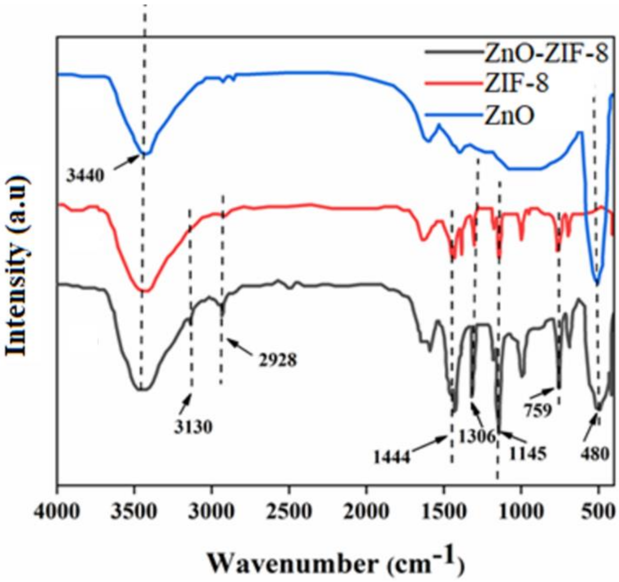


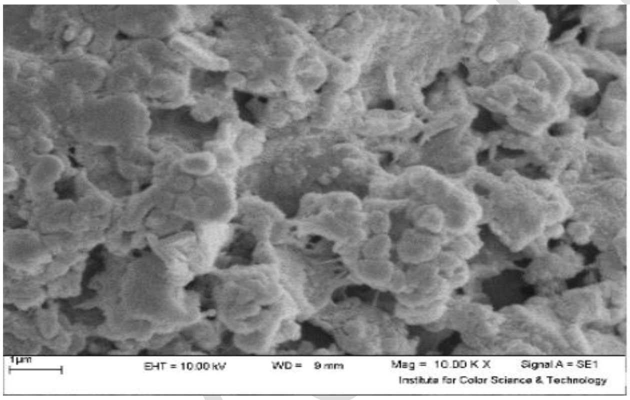
Fig. 14. FTIR spectrum of ZnO, ZIF-8, and ZnO-ZIF-8 composite (Mahmoodi *et al.,* 2021).

2.5.1.2.The role of SEM in the removal of pollution by using nanoparticles

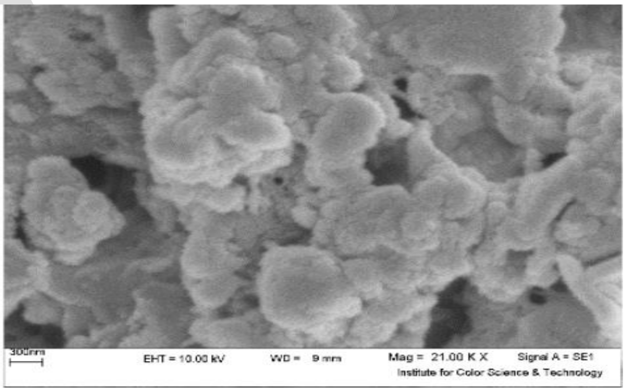
Morphology is used to determine the properties and size of SZN(0.5), SZN(1), and SZN(1.5). Fig.15 shows SEM images clearly APTES with the zeolite ,and the reaction a good combination with a diagram correct and error-free (Mahmoodi and Saffar-Dastgerdi, 2019). SEM is used to determine the porosity, shape, and size distribution of particles, and morphology of nanocomposites in Fig.16 (Mahmoodi *et al.,* 2021)

4.5.1.3.The role of XRD to removal of pollution by using nanocomposite

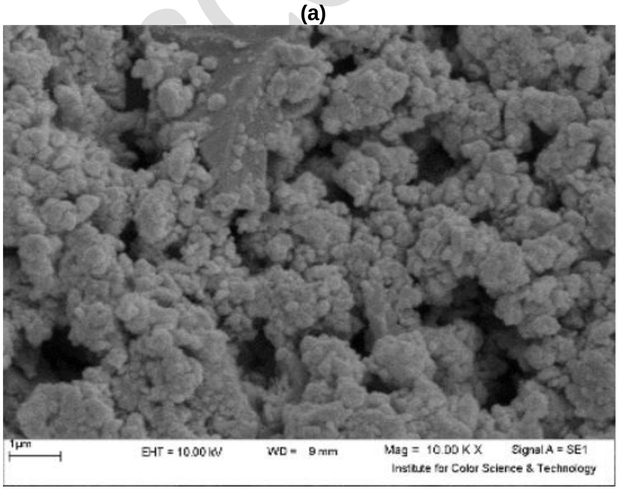
Fig.17 shows the synthesized nanocomposite with different value. Then, the central phase sodalite sample was identified through crystallography (Hailu *et al.,* 2017). The bonds in the illustration with values of 96-900-4169 have space group p-43n, a = 8.877 Å, b = 8.877 Å,c = 8.877 Å. The peaks at 14.09°, 24.54°, 34.98°, and 37.89° (2θ) are attributed to the (011), (112), (222), and (123) planes, independently, related to the sodalite zeolite peak. XRD images show that the host framework remains complete at the end, there is no significant change in the framework network ,and no change in the crystallinity of the sodalite zeolite. No change in the position of the central XRD peak was observed, indicating that APTES is located on the zeolite surface through the ion exchange (Hailu *et al.,* 2017).



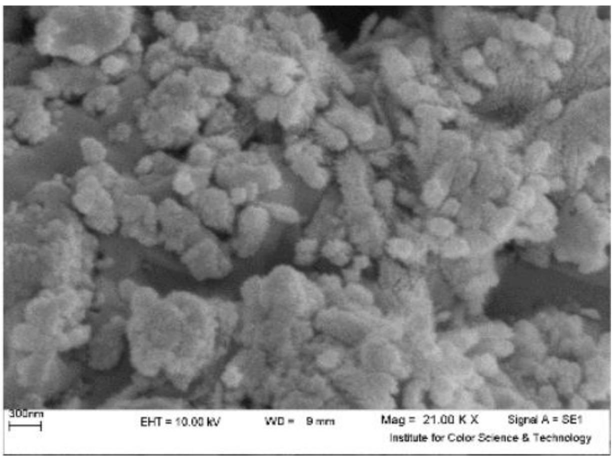
(a)



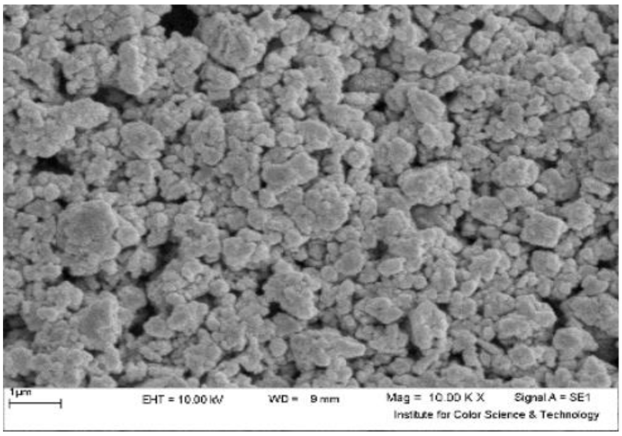
(b)

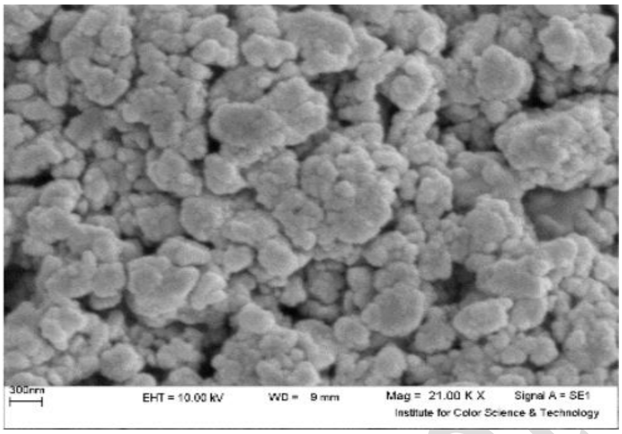


(c)

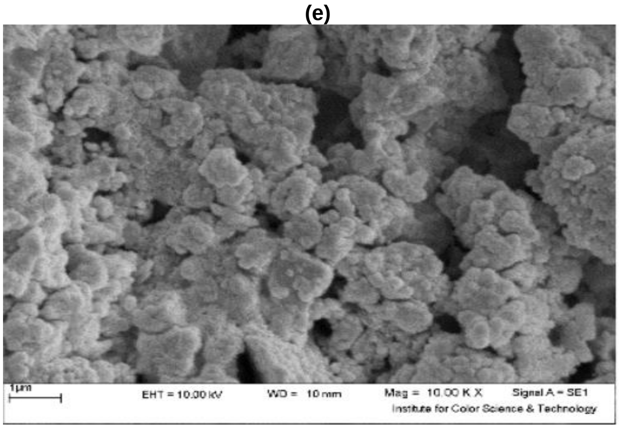


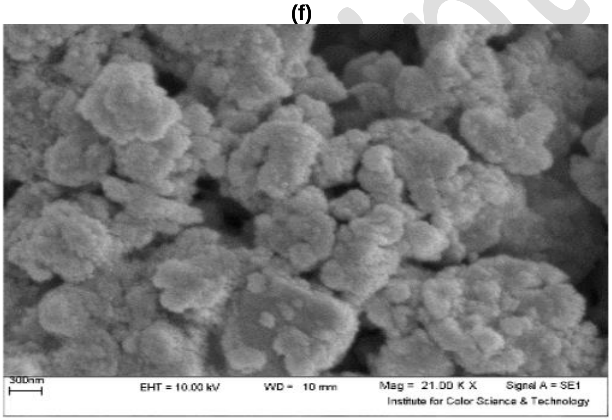
(d)





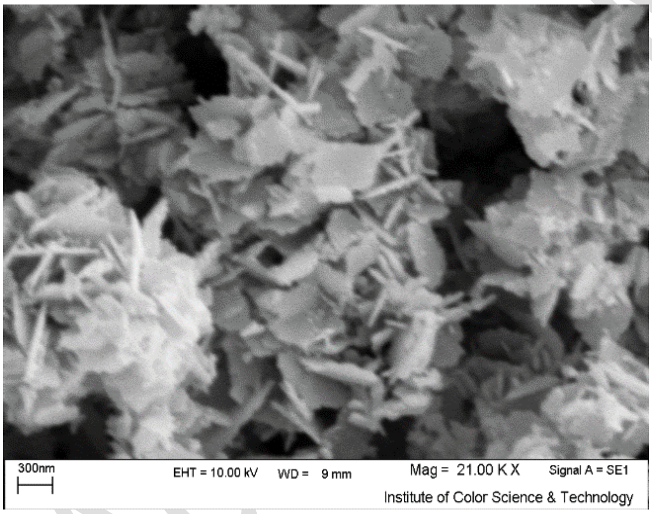
(e) (f)

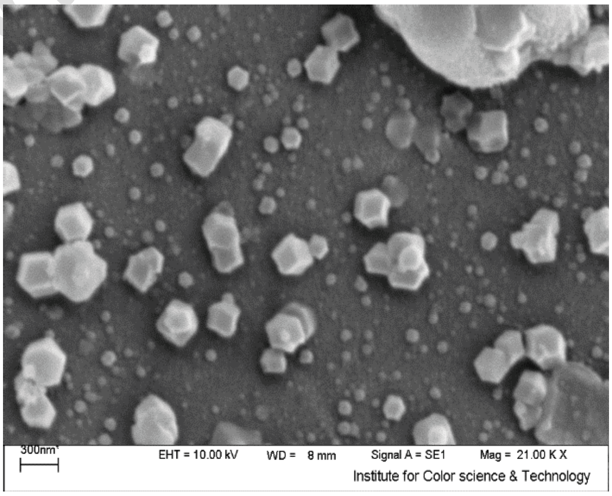




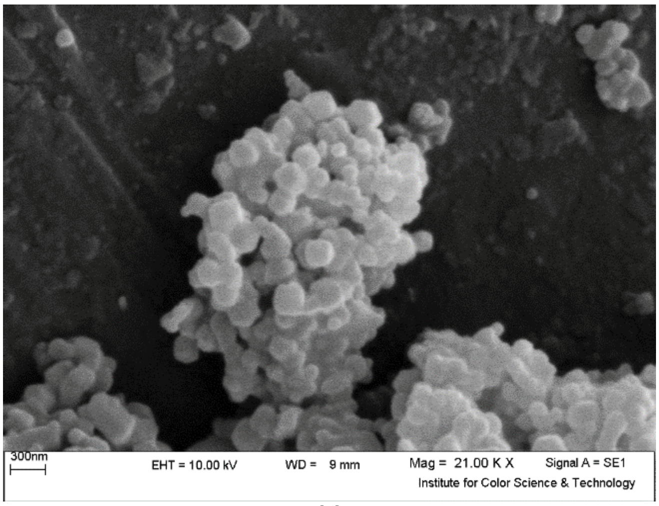
(g) (h)

Fig. 15. SEM images of (a,b) zeolite, (c,d) SZN (0.5), (e,f) SZN (1) and (g,h) SZN (1.5) (Mahmoodi and Saffar-Dastgerdi, 2019).





(a) (b)



(c)

Fig. 16. SEM images of (a) ZnO, (b) ZIF-8, and (c) ZnO-ZIF-8 composite (Mahmoodi *et al.,* 2021).

Fig.17. The XRD of different by using nanocomposite (Mahmoodi, and Saffar-Dastgerdi, 2019). The X-ray Diffraction of nanocomposites is shown in fig 18. Their peak was around 2θ = 7°,10°, 12°,18°,26° ,and 29° are observed in Fig.18. These peaks indicate the formation of a crystal structure with high crystallinity (Bustamante *et al*., 2014). Synthesized nanoparticles show sharp and intense peaks with maximum XRD peaks including 31°, 34°, 36°, 47°, 56°, 62° and 67° related to (111), (002), (101), (102), (110), (103), and (102) the surface with hexagonal is shown in the Fig. 18 (Mahmoodi *et al*., 2021). The high-intensity mentioned peaks show that the synthesized zinc oxide is well crystallized ,and has peaks of 31°,34° and 36°. The high-intensity mentioned peaks show that the synthesized zinc oxide is well crystallized, and has peaks of 31°,34°,and 36°. Thus, the peaks appearing in the range of 20-4° show the monophasic comparison of ZIF-8 growth on ZnO grains (Huang *et al*. 2006; Xie *et al.,* 2015). No additional X-ray diffraction peaks indicating impurities were found in the composite. The significant decrease in intensity of all peaks can be related to the partial coating of zinc oxide grains. In addition, this reduction peak can cause the pore blocking of ZnO grains and some changes in the ZIF-8 particle size (He *et al.*, 2019).

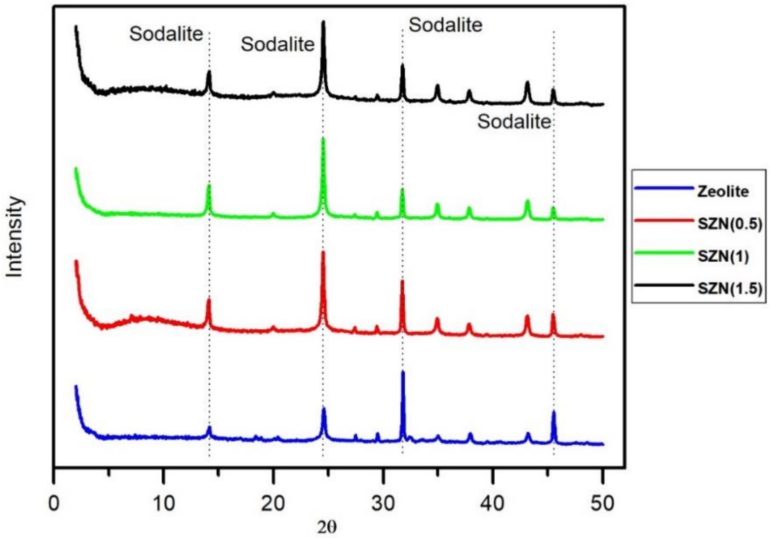


Fig. 17. XRD pattern of SZN, and Zeolite with different ratios (Mahmoodi and Saffar-Dastgerdi, 2019).

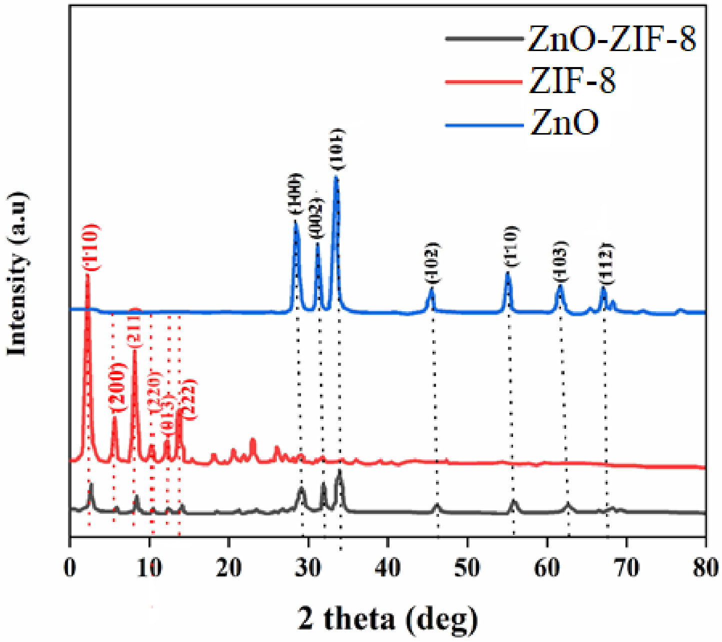


Fig. 18. XRD pattern of ZnO,ZIF-8, and ZnO-ZIF-8 (Mahmoodi *et al*., 2021).

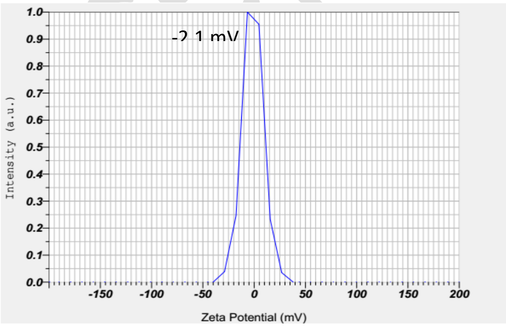
3.5.1.4.The role of zeta potential in the removal of pollution by using nanocomposite

Fig.19 concerns the zeta potential with synthesized nanocomposite, measured at pH=2.1 in optimal conditions. The peaks in the Fig.19, show the negative surface charge in zeolite ,and remain for pH tremendous than 2 (Goyal, Bulasara and Barman, 2016; Hailu *et al.*, 2017). Nanocomposite have a positive surface charge due to amine groups on the surface. The results show that there is no significant between the zeta potential worths of the nanocomposite, and it seems that the zeolite surface is saturated with a value of 2.3% by weight. In Fig. 20, the role of zeta potential is measured with 0.004 grams of nanocomposite in 100ml of water was done with ultrasonication for 30 min and the pH of value samples was 6.5.

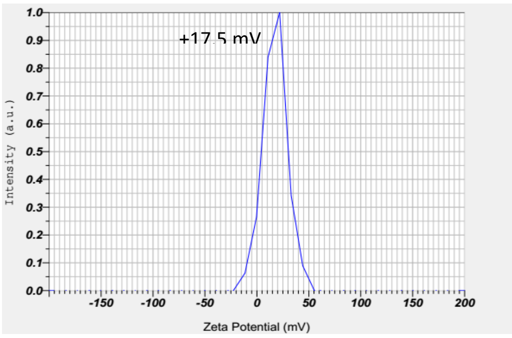
The results show that the used adsorbents have a negative surface charge in the adsorption of organic substances. Table 5 offers the adsorbent, organic pollution, the characteristics, based on the characterization, and the percentage of pollutant removal that can be obtained, which is the best method for wastewater treatment (Panahdar *et al*., 2021).

Table 5. Examination of organic pollutants using characterization.

Number	Adsorbent	Organic pollution	Characteristics	References
1	Magnetic nano-adsorbent functionalized with 8-hydroxyquinoline-5-sulfonic acid	Volatile organic compounds (BTX) vapors	FTIR,SEM,TGA/DTA, BET, VSM, XPS, EDS	Kutluay, 2021
2	Rice husk nanoadsorbent	Oryza sativa husk	FE-SEM,FTIR, EDX, AFM	Kaur, Kumari and Sharma, 2020
3	Chitosan hydrogel beads	Tricaprylmethylammonium chloride	SEM, BET, BJH	Ranjbari *et al.*, 2020
4	Polyacrylic acid-based hydrogel	Cadmium	EDX,SEM,FT-IR	Vilela *et al.,* 2019
5	Chitosan-based Hydrogel	Cadmium	EDX,SEM,FT-IR	Vilela *et al.,* 2019



(a)



(b)

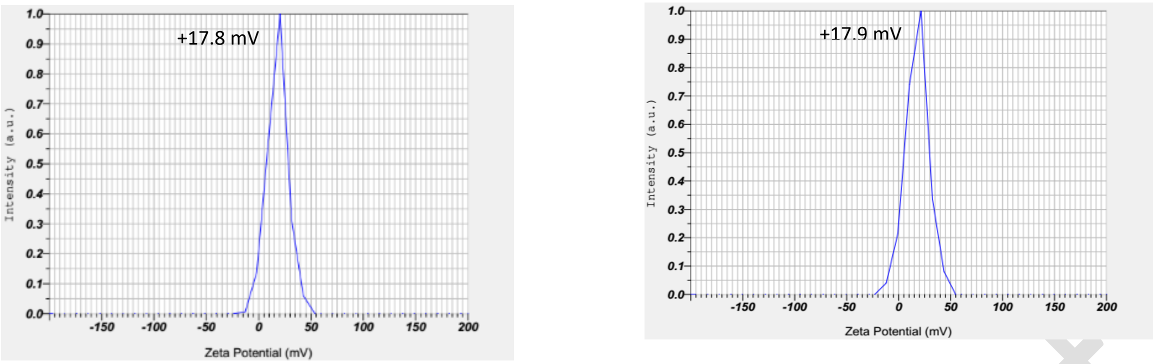
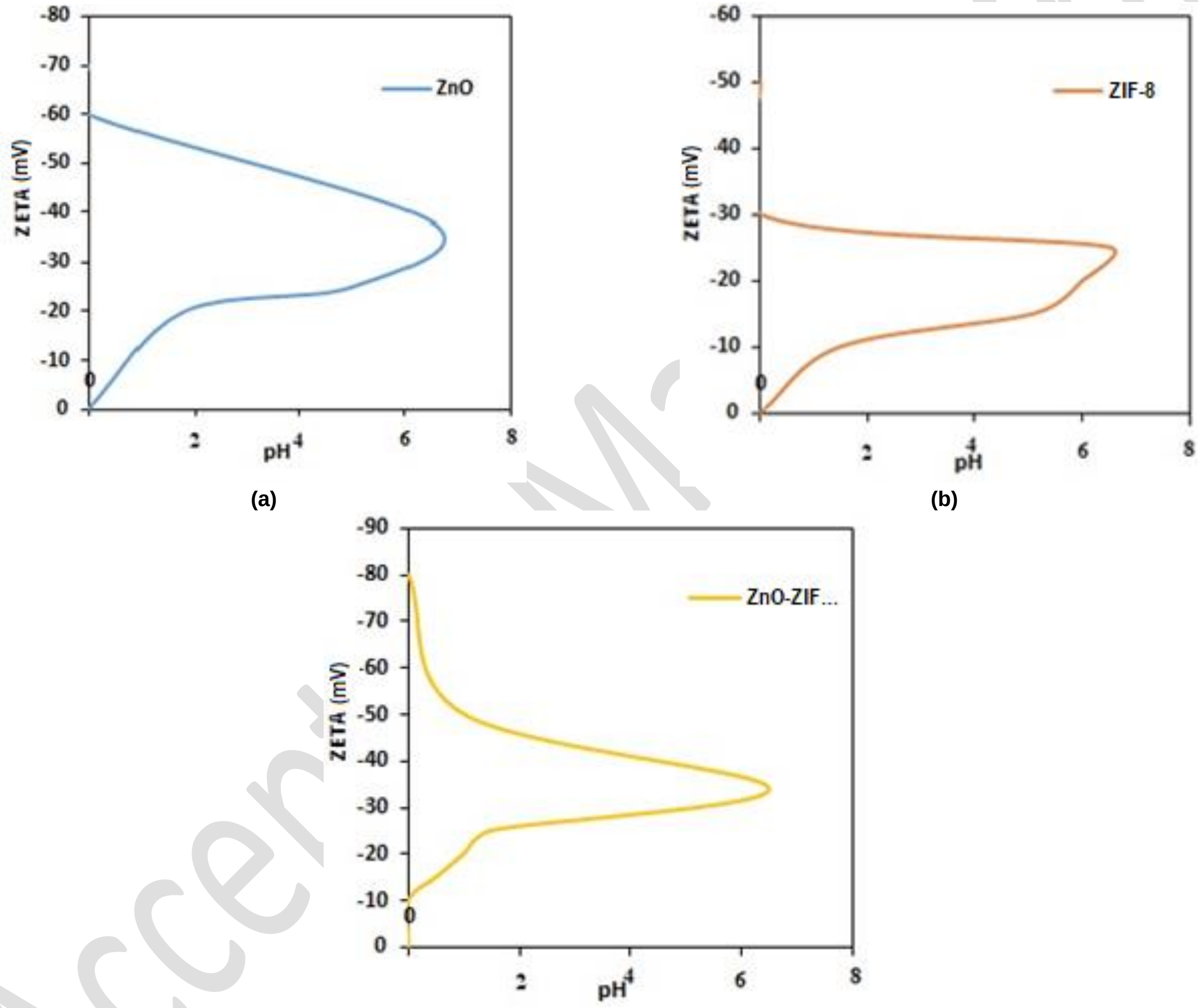


Fig. 19 . Zeta potential graph of (a) zeolite, (b) SZN(0.5), (c) SZN(1) and (d) SZN(1.5) (pH= 2.1) (Mahmoodi and Saffar-Dastgerdi, 2019).



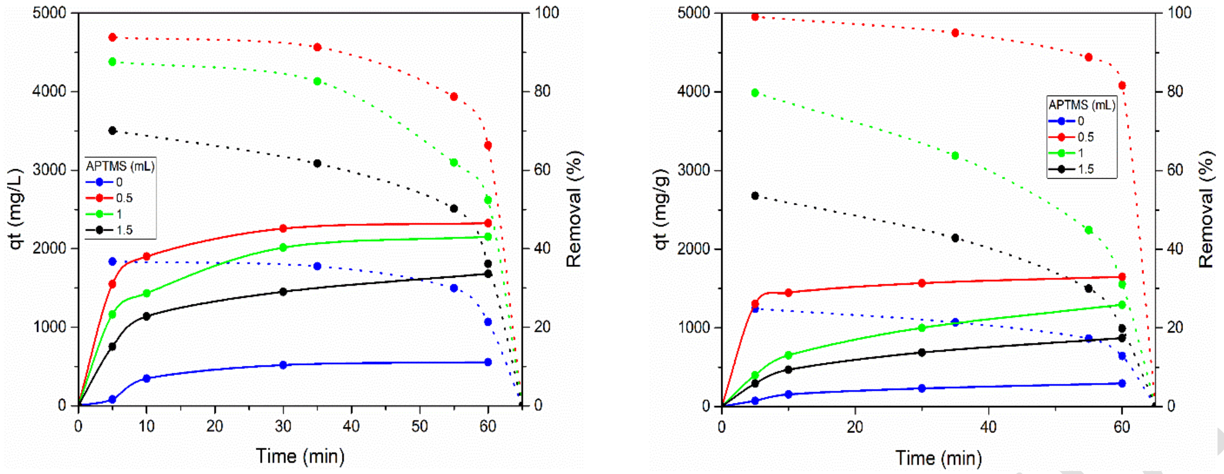
(c)
Fig. 20. Zeta potential of materials by (a) ZnO, (b) ZIF-8, and (c) ZnO-ZIF-8 (Mahmoodi *et al*., 2021).

3.6.Effect of operating parameters on adsorption processes

3.6.1.The role of γ -aminopropyltriethoxysilane on zeolite with SZN as nanocomposite

Fig. 21 offers how APTES on zeolite with SZN was obtained.The adsorption capacity decreases with increasing amount of APTES.The surface of zeolite encompasses a negative charge and other samples have a positive surface charge. The adsorption capacity of SZN (0.5) was much higher than SZN(1) ,and SZN(1.5). The zeolite surface was saturated with 0.5 mL of APTES and the remaining amounts of APTES caused problems within the pores or cavities of SZN(1), and SZN(1.5) by APTES.

In expansion, the interactions between most groups of APTES on the adsorbent surface were improved (Liu *et al.,* 2013).

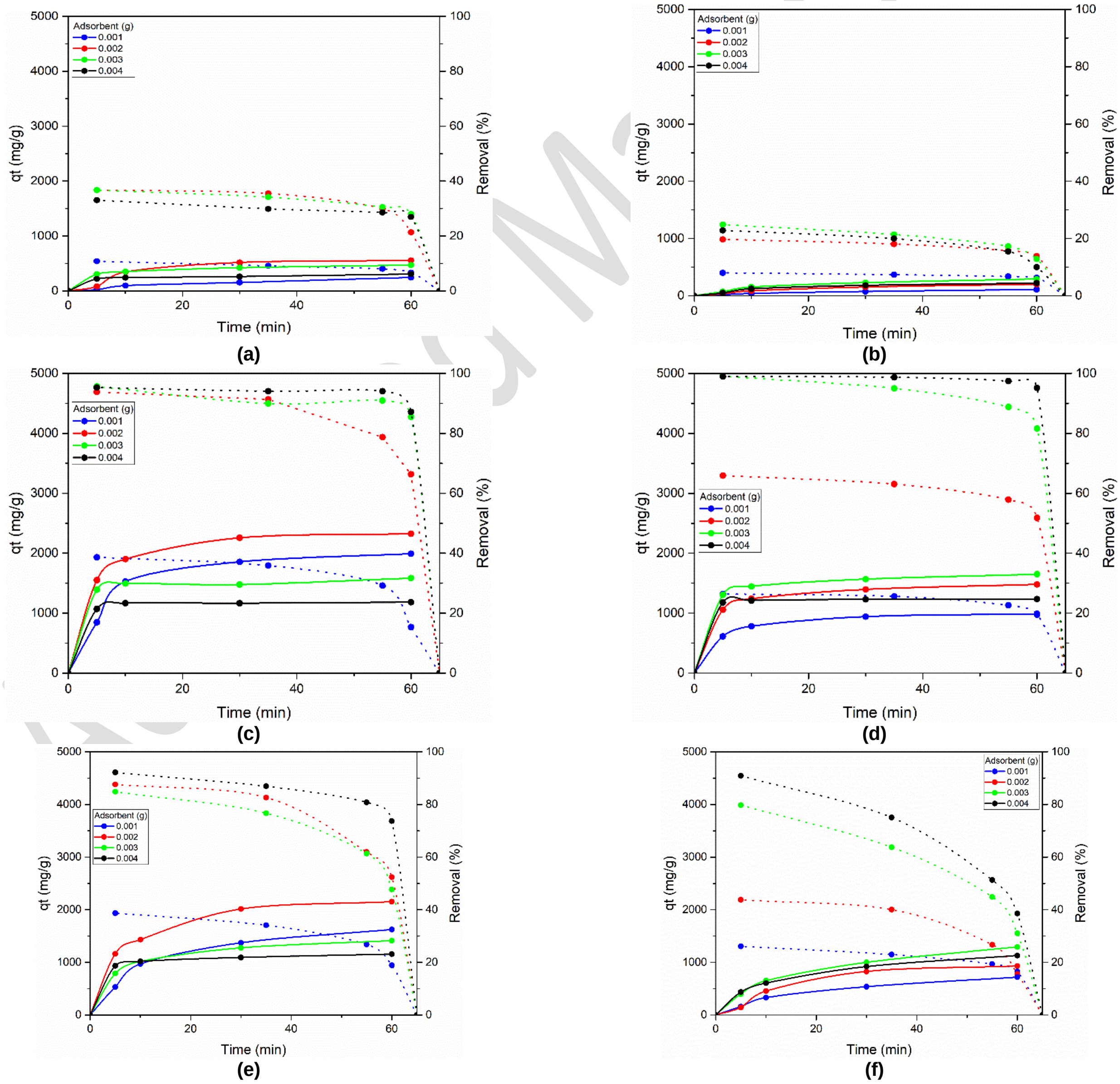


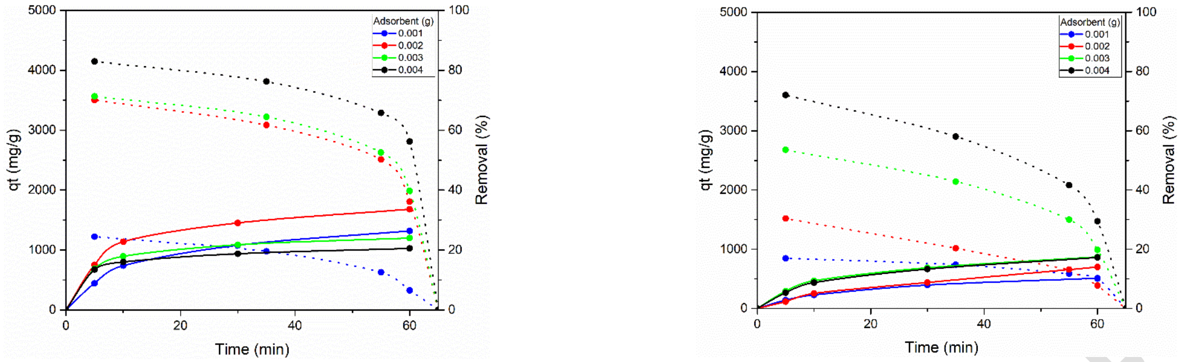
(a) **(b)**

Fig. 21. Effect of APTES on zeolite, and SZN by organic pollutions (Mahmoodi and Saffar-Dastgerdi, 2019).

3.6.2. The role of adsorbent dose by using nanocomposite

The effective parameters of an adsorbent on adsorption are shown in Fig. 22. The increase of nanocomposite from 0.001 to 0.004g has increased pollutant removal the number of adsorption sites, and investigation adsorbent capacity (qe (mg/g)) (Liu *et al.,* 2013). Here, shows that qe causes a reduction of an adsorbent capacity (qe (mg/g)) and can cause increasing the adsorbent concentration gradient in the solution and the adsorbent surface. Thus, increasing the adsorbent in the pollutant can cause a decrease in the qt value (Liu *et al.,* 2013).





(g) (h)

Fig. 22. Effect of adsorbent dose on pollutant removal by Zeolite ,and SZN (Mahmoodi and Saffar-Dastgerdi, 2019).

3.6.3. The role of Initial concentration by using nanocomposite

Fig. 23 concerns the adsorption of nanocomposite with other initial concentrations including 50,75,100, and 125 mg/liter. Increasing the initial concentration causes SZN(0.5) pollutant adsorption to increase and pollutant removal to decrease (Napia *et al.,* 2012).

3.6.4. The role of pH Solution by using nanocomposite

Fig.24 concerns the pH solution to remove pollutants. Investigations show that the capacity of adsorbent to treat organic pollutants depends on the surface charge material and the pH solution (Tahir, Bhatti and Iqbal, 2016; Garg, *et al.,* 2015; Graba *et al.,* 2015). Table 6 concerns the adsorbent, organic pollutants, optimal conditions, and correlation coefficient. The parameters affecting adsorption can be obtained based on the initial concentration, adsorbent dose, temperature, and pH solution. The correlation coefficient plays an essential role in wastewater treatment. As much as this value is close to one, it means that the results work have been done correctly and without errors (Mahmoodi and Saffar-Dastgerdi, 2019).

3.7.The effect mechanisms of nano adsorbent for removal of pollution

Nanoparticles play an essential role in wastewater treatment and by using other reagents, pollutants can be removed well. According to the research on nanocomposites with other oxides, including Zirconium dioxide, Aluminum oxide, Silicon dioxide, and Zinc oxide, they have a high adsorption potential. In addition, there are promising results regarding the analysis of rare metals for water treatment and alkaline salt solutions with High purity percentages have shown that separating nanoparticles from aqueous solution is one challenge in that wastewater and water treatment are tiny and scattered. According to the research, the adsorption efficiency depends on the pH solution, the lower and higher the pH solution, there is a big difference in obtaining the isoelectric point oxide (Song *et al.,* 2014; Shen *et al.,* 2017; Abbasi et al., 2023).

Table 6. Comparison of organic compound, and condition adsorption methods to make the correlation coefficient.

Number	Adsorbent	Organic pollution	Condition adsorption	Correlation coefficient	References
1	Ricehusk nanoadsorbent	Oryza sativa husk	pH=8,contact time= 70 min ,temperature =60° C ,0.6 g/50 mL nanoadsorbent dose	0.9991	Kaur, Kumari and Sharma, 2020
2	Chitosan hydrogel beads	tricaprylmethylammonium chloride	nanoadsorbent dose = 3 mg/ L, pH= 7 , temperature= 25,35, 45 °C, contact time=45 min , C0=10,30,50	90% removal efficiency	Ranjbari *et al.,* 2020
3	Chitosan-based hydrogels	Cadmium	pH=6, temperature= 313K, contact time = 1440 min; 100.0 mg adsorbent mass; 50 mL solution volume	0.9889,0.9670 ,0.9997	Kutluay, 2021
4	Magnetic nano-adsorbent functionalized with 8-hydroxyquinoline-5-sulfonic acid	volatile organic compounds (BTX) vapors	Retention time (min) =70.17, 75.65, 79.36 ,InletBTX concentration (mg/L),= 31.96,34.41 29.80, temperature (℃) =25.52,25.98,26.03 ,Predicted adsorption capacity (mg/ g) = 558.72, 622.93, 750.21 ,Observed adsorption capacity (mg/ g) 555.85, 620.80, 745. 54	91.92%, 91.17% ,90.65%	Vilela *et al.,* 2019
5	Polyacrylic acid-based hydrogel	cadmium	contact time=1440 min; 100.0 mg adsorbent mass; 50.0 mL solution volume,pH=6,temperature= 313K	0.9738,0.9881 ,0.9808	Vilela *et al.,* 2019

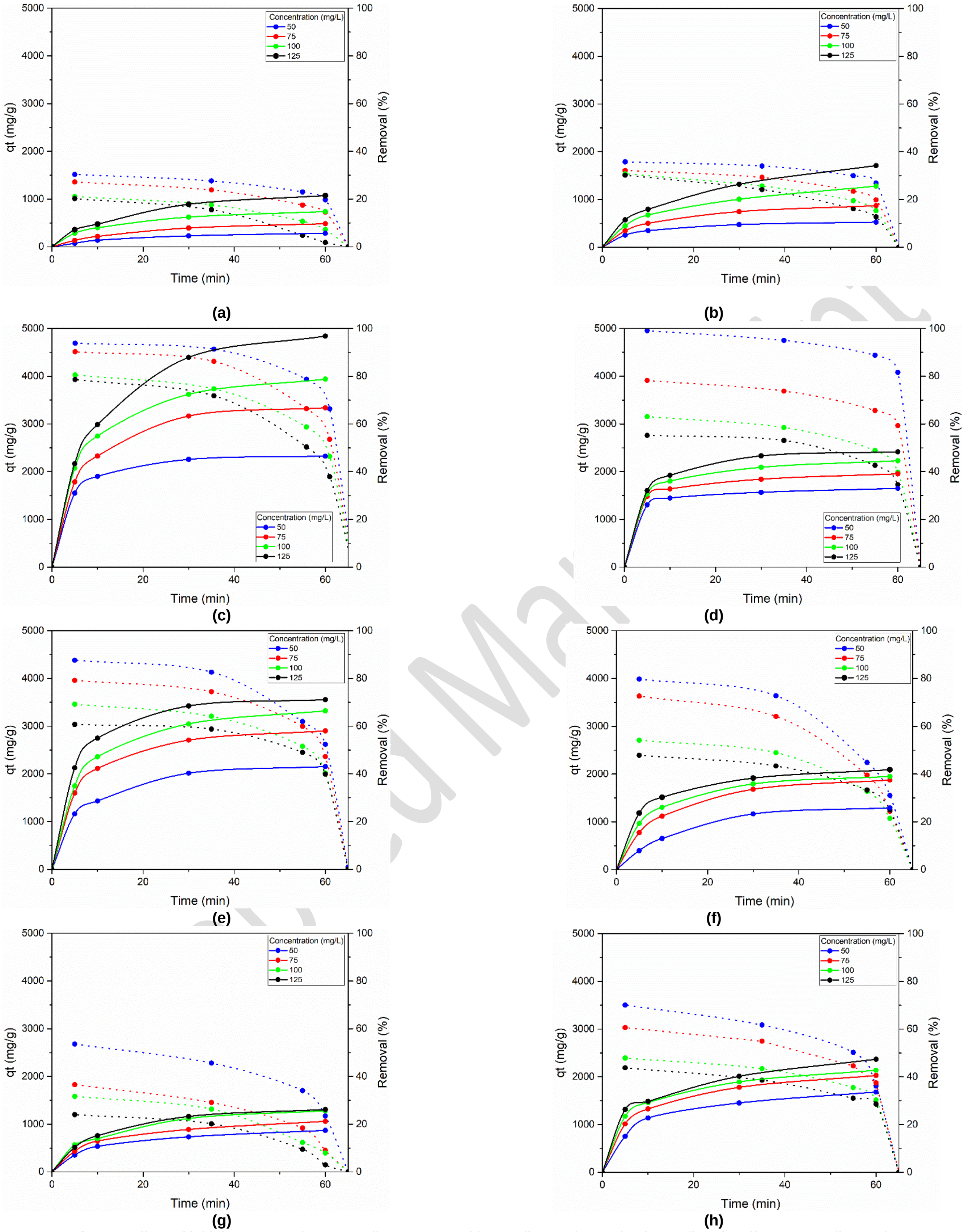
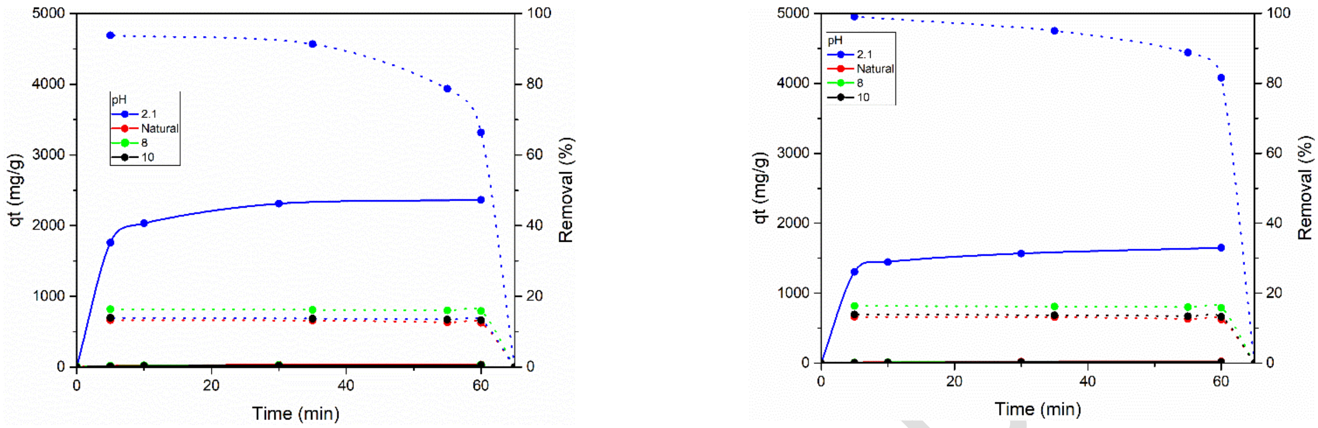


Fig. 23. Effect of initial concentrations on pollutant removal by Zeolite, and SZN (Mahmoodi and Saffar-Dastgerdi, 2019).

3.7.1.The role of activated carbon in wastewater treatment

Wastewater treatment has other methods; carbon-based adsorbents have a tremendous effect in deciding wastewater treatment. Because this porous material has a stable structure in the environment and is non-toxic, this method is beneficial in deciding high adsorption, (Machida, Mochimaru and Tatsumoto, 2006). Single-walled carbon nanotubes, graphene, and activated carbon are primarily used in adsorption processes (Chen *et al.,* 2007; Sharma et al., 2009). Activated carbon is connected with the adsorbent material through the van der Waals force, which plays an essential role in porous filling and surface area. Activated carbon can show acidic ions to absorb metal ions through ion exchange (Machida, Mochimaru and Tatsumoto, 2006; Apul *et al.,* 2013). Granular activated carbon (GAC)

and powder activated carbon (PAC) are two activated carbons in which GAC is suitable as an adsorbent for removing organic pollutants found in fibers and pellets (Ren *et al.,* 2011; Ali *et al.,* 2013; Fu *et al.,* 2015). The vital characteristics of activated carbon are molecular size, surface active groups, particle size distribution, solubility (Ramesha *et al.,* 2011; Zare *et al.,* 2015; Apul *et al.,* 2013; Chen *et al.,* 2007).
Activated carbon is used for agricultural waste, coconut shells, and wood and coal derivatives, which has an essential and fundamental application in removing pollutants by (Gupta, 2009; Chatterjee, Lee and Woo, 2010). Kanawade and Gaikwad (2011) focused on pollutant removal and isotherm model investigation with three other concentrations of 5,10, and 20 mg/L in 80 min and 27°C (Kanawade and Gaikwad, 2011). Pathania, Sharma and Singh (2017) said that they removed pollutants on the surface through activated carbon at pH=7.8 and with the kinetic method, pseudo-second-order model, and intraparticle diffusion model, they were able to check the correlation rib and the adsorption method (Pathania, Sharma and Singh, 2017). The investigation reached a favorable and suitable result (Lorenc-Grabwska *et al.,* 2007).



(a) **(b)**

Fig. 24. Effect of solution pH on pollutant removal by Zeolite, and SZN (Mahmoodi and Saffar-Dastgerdi, 2019).

3.7.2. The investigation of graphene oxide in wastewater treatment

Graphene, a two-dimensional layer carbon family, has physical; chemical; mechanical, and electronic properties, that have essential and essential features, such as high optical transparency, thermal conductivity, compressive strength, and a large surface along with a large pore volume (Al-Degs *et al.,* 2001; Lillo-Ródenas *et al.,* 2007; Bina *et al.,* 2012). Active groups in graphene oxides have carbonyl, hydroxyl, and epoxy, widely used in wastewater treatment (Kanawade and Gaikwad, 2011). Due to its magnetic properties, it is possible to separate liquid from solid. Reduced graphene oxide and reduced graphene oxide play an essential role in removing organic pollutants from wastewater (Kanawade and Gaikwad, 2011). Graphene oxide is biodegradable as an adsorbent with an adsorption (Pathania, Sharma and Singh, 2017). Ramesha *et al.*, 2011 said on two GO that the removal efficiency of pollutants in reduced and reduced graphene oxide used was 95 %. (Apul *et al.,* 2013) said that graphene oxide plays an essential role in removing organic pollutants (Wang *et al.,* 2014;Robati *et al.*, 2016) investigated the removal efficiency of graphene oxide pollutants in 100 min with solution pH=3 (Upadhyay *et al.,* 2014; Kyzas, Deliyanni and Matis, 2014).

3.7.3.The investigate carbon nanotubes in wastewater treatment

Carbon nanotubes play an important role in chemical, electrical, physical, mechanical and semiconductor properties (Mishra and Ramaprabhu, 2011; Kyzas, Deliyanni and Matis, 2014). The specific surface area, layered and hollow structure of carbon nanotubes are important factors that make them ideal adsorbents for removing organic and inorganic pollutants such as heavy metals, arsenic, lead, 1,2-dichlorobenzene, radionuclides and organic substances (Mishra and Ramaprabhu, 2011; Allen, Tung and Kaner, 2009; Apul *et al.,* 2013; Kyzas, Deliyanni and Matis, 2014; Robati *et al.,* 2016; Khourshidi and Qaderi, 2023). Carbon nanotube adsorbents adsorb through various interactions and forces, including hydrogen bonding, vander Waals forces, hydrophobic interactions, noncovalent forces, and the presence of π-π bonds (Stafiej and Pyrzynska,2007). Gong *et al.*, 2009 discussed the effectiveness of removing organic pollutants by multi-walled carbon nanotubes based on the Freundlich model (Peng *et al.,* 2003; Yao *et al.,* 2010) improved the adsorption efficiency of organic pollutants by using multi-walled carbon nanotubes, increasing the removal efficiency from 55.34mg/g to 46.2mg/g (Ren *et al.*, 2011; Ai *et al.*, 2011) took the organic pollutants of multi-walled carbon nanotubes by considering contact time, pH solution, and initial dye concentration as the practical adsorption. They found that the adsorption capacity was 48.06 mg/g (Sadegh *et al.,* 2015; Kaydi *et al.*, 2012) reported that the adsorption capacity of multi-walled carbon nanotubes was 108.97 mg/g (Pyrzynska, 2011; Vinod Gupta *et al.,* 2013) suggested that maximum adsorption of contaminants occurs due to electrostatic interactions and π-π bonds (Pyrzynska, 2011; Vinod Gupta *et al.,* 2013).

3.7.4. The investigate Zirconium-modified activated with phosphate in wastewater treatment

A suitable adsorbent containing zirconium (Zr(IV)-AS) effectively removed phosphate from aqueous solutions. The results revealed that zirconium was precisely placed on the activated sludge (AS). The specific surface area and pore volume have been greatly improved. Zr(IV)-AS demonstrated a high phosphate adsorption capacity, with a maximum of 27.55mg P·G-1 at 25°C.

The Langmuir model may accurately represent phosphate adsorption isotherms, while the pseudo-second-order model describes adsorption kinetics. The adsorption of phosphate on Zr(IV)-AS increased as the pH of the solution. The presence of SO_4^{2-} in water reduced the adsorption capacity of zinc phosphate adsorbent at high concentrations (25mmol/L), while the effect of HCO_3^- on adsorption capacity can increase the pH of the solution. The adsorption properties of phosphate in wastewater can satisfy the requirement of phosphorus needs of the China National Wastewater Treatment Organization. Zr(IV)-AS saturated with phosphate in 0.1 mol/L NaOH solution is adsorbed and reusable adsorbent has a high capacity due to electrostatic interaction ,and anion exchange on the surface of Zr(IV)-AS, which may be purified again (Wang, Tong and Wang, 2018).

3.7.5. The investigate zinc oxide and iron oxides in wastewater treatment

Pollutants ,such pesticides, and heavy metals have been found in water, and their accumulation in drinking water poses a significant risk. It is critical to the health of humans and other species in the environment as it causes bone abnormalities, neurological diseases, liver damage, and cancer. There is a need to remove contaminants from water, particularly those that can be handled via adsorption (Bharti *et al.*, 2022).

3.7.6. The investigate alumina based nanomaterials in wastewater treatment

Because of their high surface area, porous nature, huge number of active sites, creation of a stable meta phase, and hexagonal structure, alumina (Al_2O_3) nanocomposites are critical in pollution removal. Nano alumina can be applied to membranes and nanocomposites to remove contaminants. Alumina can completely purify wastewater while also preventing disease spread (Mahesh *et al.,* 2023).

3.7.7. The investigate nano-sized zinc oxide in wastewater treatment

Zinc oxide nanotechnology removes pollutants from aquatic environments due to its nano dimensions and numerous properties, such as surface area. Nano-sized zinc oxide plays an essential role as non-toxic and cost-effective. Zinc oxide is synthesized by various methods ,such as green synthesis, sol-gel method, and co-precipitation. The mechanism of pollutant removal by nano-sized zinc oxide uses photocatalyst, sonolysis, adsorption, coagulation, and ozonation for wastewater treatment (Aremu *et al.,* 2021).

3.7.8. The investigate Cadmium Ion by Nano-metal Oxides in wastewater treatment

Heavy metals can be detrimental to both humans and the environment. They are not biodegradable and tend to bioaccumulate in other concentrations. Adsorption is a cost-effective strategy. Cadmium metal for example, can enter the water through the discharge of industrial pollutants, which can be effectively treated with the adsorption method (Kumar and Chawla, 2014).

3.8. The investigation of organic pollution as adsorbent by isotherm, kinetic, and thermodynamic using adsorption methods

There are several models for obtaining adsorption including isotherm, kinetic, and thermodynamic and each of these organic molecules is dependent on the type of adsorbent. Tables 7-9 depict the isotherm, kinetics, and thermodynamics of adsorption processes. Table 10 shows the adsorbent, organic pollution, isotherm, kinetics, adsorption capacity, and thermodynamics, using the formula for these instances, the optimal value can be determined.

Table 7. Use of adsorption isotherm equations to the remove pollutions

Number	Models	Equations	References
1	Langmuir	$qe = \frac{Q0bCe}{1+bCe}$	(Wilhelm Schabela, 2007)
2	Freundlich	$\mathrm{qe} = \mathrm{KFCe}^{\frac{1}{n}}$	(Wilhelm Schabela, 2007)
3	Dubinin–Radushkevich	$(qe)\,\exp(-Kadd\varepsilon^2)$	(Dada, 2012)
4	Temkin	$qe = \frac{RT}{bT} lnATCe$	(Wilhelm Schabela, 2007)
5	Flory–Huggins	$qe = \frac{\theta}{C0} = KFH(1-\theta)^{nFH}$	Rahman *et al.,* 2019
6	Hill	$\mathrm{qe}=\frac{qsHCe^{nH}}{KD+Ce^{nH}}$	(Wilhelm Schabela, 2007)

Table 8. Use of adsorption kinetic equations to the remove pollutions.

Number	Models	Equations	References
1	Pseudo first order	$\mathrm{qt}=\mathrm{qe}\left(1-e^{(-\mathrm{k1t})}\right)$	Singh and Majumder, 2015
2	Pseudo second order	$\mathrm{qt} = \frac{k2qe^2t}{1+\ k2\mathrm{q}et}$	Singh and Majumder, 2015
3	Intra particle diffusion	$\mathrm{qt}= \mathrm{Ki}\sqrt{\mathrm{t}} + \mathrm{Ci}$	Singh and Majumder, 2015
4	Elovich	$q_t=\beta\ln(\alpha\beta)+\beta\ln(t)$	Singh and Majumder, 2015
5	Bangham	$\mathrm{qt} = \mathrm{logk} + \frac{1}{b} logt$	Singh and Majumder, 2015

Table 9. Thermodynamic equations.

Number	Eqs.	Reference
1	$\Delta G = \Delta H - T\Delta S$ $\mathrm{Kd} = \mathrm{qe/Ce}$ $\mathrm{Ln\,Kd} = \Delta S/R - \Delta H/RT$	Thirunavukkarasu, Nithya and Sivashankar, 2020

Table 10. Isotherm, kinetics, Qmax and thermodynamics of various adsorbents to remove various pollutants.

Number	Adsorbent	Organic pollution	Qmax	Isotherm	Kinetic	Thermodynamic	References
1	Rice husk nanoadsorbent	Oryza sativa husk	6.101	Freundlich,Langmuir, Temkin	Pseudo-first order, Pseudo-second order, Intraparticle diffusion	ΔG = -12.19,-12.62,13.06, -13.48, -13.93, -14.35 ΔS =43.14 ΔH =14.634	Kaur, Kumari and Sharma, 2020
2	Chitosan hydrogel beads	Tricaprylmethylammonium chloride	20.85	Langmuir, Freundlich, Sips	pseudo-first-order, pseudo-second-order, Weber and Morris intra-particle diffusion model	ΔG°=5.764, 3.958, 2.796 ΔH°= 49.148 Δs°=145.86	Ranjbari *et al.,* 2020
3	Magnetic nano-adsorbent functionalized with 8-hydroxyquinoline-5-sulfonic acid	Volatile organic compounds (BTX) vapors	745.54	Langmuir, Freundlich, Dubinin–Radushkevich	pseudofirst-order, pseudo-second-order	_	Kutluay, 2021
4	Polyacrylic acid-based hydrogel	Cadmium	197.92	Non-linear Langmuir, Freundlich,	Non-linear pseudofirst-order, pseudo-second-	ΔG°=−8.1,−11.6,−16.4 ΔH°= 57.7 ΔS°=236.8	Kutluay, 2021

				Redlich-Peterson and Sips isotherm models	order and Elovich kinetic models		
5	Chitosan-based hydrogel	Cadmium	234.83	Non-linear Langmuir, Freundlich, Redlich-Peterson and Sips isotherm models	Non-linear pseudofirst-order, pseudo-second-order and Elovich kinetic models	ΔG°=−9.7,−10.8 ,−12.3 ΔH°= 11 ΔS°= 74.4	Vilela *et al.*, 2019

4. Conclusions

Today, people worldwide are facing severe, water shortages despite the abundance of water sources. Water is a precious and essential resource for humans. However, with the increase in population and the increase in various industries and environmental changes, it is a serious and dangerous threat to humans, animals, aquatic life, and the environment. The presence of organic pollutants in water is hazardous threatens health and causes various diseases. Adsorption is considered the most practical method for purifying water containing organic pollutants. Polymer composites and nanocomposites are of significant importance as an adsorbents and for cost-effective, highly Namenclacure concentrated, and environmentally friendly processing. Many scientists in this field and different industries use this method, and surface adsorption is the best method for purifying organic pollutants in wastewater and water. Polymer nanocomposites have attracted considerable attention due to their ability to remove a wide range of organic pollutants through adsorption mechanisms. The results show that the presence of pollutants in water has a harmful effect on quality, color, and taste. It means that we have to look for the best method to remove pollutants, considering the increase in population and industries, we have to choose the best method to have clean water without salts.

Namenclatur

Full name	Abbreviation
Polychlorinated biphenyls	PCBs
Polycyclic aromatic hydrocarbon	PAHs
Polybrominated diphenyl ethers	PBDE
Polychlorinated biphenyl	PCB
Dichlorodiphenyltrichloroethane	DDT
Persistent organic pollutants	POPs
Layered double hydroxides	LDHs
Santa Barbara Amorphous	SBA
sodalite zeolite nanoparticles	SZN
γ-aminopropyltriethoxysilane	APTES
X-ray photoelectron spectroscopy	XPS
Energy Dispersive X-ray Spectroscopy	EDS
X-ray Diffraction	XRD
Scanning electron microscopy	SEM
Transmission electron microscopy	TEM
Energy dispersive X-ray analysis	EXD
Brunauer-Emmett-Teller	BET
Fourier-transform infrared spectroscopy	FTIR
Thermogravimetric analysis	TGA
Definitions of Differential Thermal Analysis	DTA
Vibrating-sample magnetometer	VSM
Field emission scanning electron microscopy	FE-SEM
Atomic Force Microscopy	AFM
Barrett-Joyner-Halenda	BJH
Chemical Oxygen Demand	COD
Total Organic Carbon	TOC
Biochemical Oxygen Demand	BOD
Santa Barbara Amorphous	SBA
Mesoporous Molecular Sieve	MCM
Metal–organic frameworks	MOFs
Carboxylated chitosan	CCS
Zeolitic imidazolate framework	ZIF-8

Author Contributions

Ali Hosseinian Naeini: Writing – original draft , writing – review, writing – editing, conceptualization, resources, investigation, methodology.

Conflict of Interest

The author declares no competing interests.

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Data Availability Statement

All data used in this study are included in the manuscript.

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