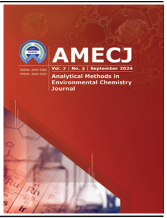
Anal. Methods Environ. Chem. J. 7 (3) (2024) 51-82

Research Article, Issue 3
Analytical Methods in Environmental Chemistry Journal
Journal home page: www.amecj.com/ir



A review in analytical methods: Removal and extraction of pollutants in different matrixes by nanotechnology

Mohammad Reza Rezaei Kahkha[a], Ali Faghihi Zarandi[b,*], Hasti Daraei[c,d], Alireza Nasiri[d], Somayyeh Karami-Mohajeri[e], Maryam Faraji[c,d], Hamideh Asadollahzade[f], Fatemeh alsadat Bahador[b], and Anahita Hejazi[b]
[a] PhD in Analytical Chemistry Department of Environmental Health Engineering, Zabol University of Medical Sciences, Zabol, Iran
[b] Department of Occupational Health Engineering and Safety at Work, Faculty of Public Health, Kerman University of Medical Sciences, Kerman, Iran
[c] Department of Environmental Health Engineering, Faculty of Public Health, Kerman University of Medical Sciences, Kerman, Iran
[d] Environmental Health Engineering Research Center, Kerman University of Medical Sciences, Kerman, Iran
[e] Department of Toxicology and Pharmacology, Faculty of Pharmacy, Kerman University of Medical Sciences, Kerman, Iran
[f] Department of Chemistry, Faculty of Science, Kerman branch, Islamic Azad University, Kerman, Iran, P. O. Box 7635131167, Kerman, Iran

ARTICLE INFO:
Received 14 Apr 2024
Revised form 12 Jun 2024
Accepted 16 Aug 2024
Available online 30 Sep 2024

Keywords:
Removal,
Pollutants,
Nanotechnology,
Adsorbents,
Analytical methods,

ABSTRACT

The field of nanotechnology has demonstrated remarkable potential in effectively addressing environmental issues through remediation, particularly in extracting and removing pollutants from water, air, and human samples. The unique properties of nanomaterials, such as their high surface area (HSA) to volume ratio, size, and optical and magnetic behavior, make them well-suited for various applications in pollution control in different matrixes. Nanotechnology-based adsorbents are utilized in multiple fields such as water wastewater treatment, air purification filters, photocatalysis, environmental monitoring, electrochemical sensors, industrial, human sample analysis, and bioanalysis. Nanoadsorbents such as carbon nanotubes (CNTs), graphene (G), metal oxide nanoparticles(MONPs), metal-organic frameworks (MOFs), nanocomposites, magnetic nanoparticles, and silica-based nanomaterials are materials at the nanoscale that can remove pollutants by solvent extraction, membrane separation, photocatalysis, sorption, filtration, adsorption, precipitation, ion exchange, bioremediation, phytoremediation, coagulation, flocculation, and chemical oxidation/reduction technique. These nanomaterials are designed to have high surface areas and unique properties that effectively absorb various contaminants. The choice of nano adsorbent depends on the specific pollutants targeted, the environmental conditions, the physicochemical characteristics of the pollutant, and the desired application. Ongoing research is exploring new nanomaterials and optimizing existing ones to improve efficiency and address potential environmental and safety concerns. In summary, nanotechnology holds great potential for extracting and removing pollutants in water, air, soil, and human samples, using innovative methods for environmental protection and public health.

1. Introduction

Environmental pollution results from human activities introducing harmful substances into the environment, causing negative impacts on the environment and ecology. An instance of this is wastewater discharge into surface water sources such as tanks and rivers, a form of water pollution. Pollutants are substances or agents introduced into the environment that cause harm or discomfort to living organisms. These pollutants can be classified into various categories based on their origin, physical state, and environmental impact.

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*Corresponding Author: Ali Faghihi Zarandi
Email: alifaghihi60@yahoo.com
https://doi.org/10.24200/amecj.v7.i03.1004

One of the important types of pollutants are VOCs, BTEX, and organic materials. Volatile Organic Compounds (VOCs) and organic materials can serve as pollutants in water and air and pose potential health risks to humans [1-3]. Industrial processes and indoor sources such as manufacturing, painting, printing, chemical production, building materials, and household products can release VOCs into the air [1,2]. Also, vehicle emissions include the combustion of fossil fuels, which releases VOCs and other organic compounds. VOCs can react with other atmospheric pollutants, contributing to ground-level ozone and smog formation. High exposure to VOCs may cause respiratory irritation, headaches, and potential long-term health effects [4,5]. Factories and manufacturing facilities may release VOCs and other organic pollutants into soil and water bodies. Pesticides, fertilizers, and herbicides can introduce organic compounds into water systems. Stormwater can carry pollutants from roads, parking lots, and urban areas into water bodies. VOCs can contaminate drinking water sources and affect the aquatic ecosystem [6,7]. Organic pollutants may accumulate in aquatic organisms, leading to biomagnification in the food chain. Consumption of contaminated water may result in health issues, including gastrointestinal and neurological effects. Inhalation of VOCs, ingesting contaminated food and water, and direct skin contact with contaminated materials cause respiratory problems in rats [8]. According to the serious health effects of VOCs, analyzing biological samples (blood, urine) to assess human exposure to chemical pollutants and monitoring air and water quality is needed to further evaluate risk assessment and consequent control and mitigation by regulation of governments and environmental agencies. Therefore, controlling or reducing the emission of pollutants is achieved by establishing and implementing environmental regulations and standards [9]. The enforcement of regulations on industrial emissions, vehicle standards, and water quality to limit VOC/BTEX and organic material pollution is required. Technological solutions, including implementing air and water treatment technologies, could effectively remove or reduce VOCs and organic pollutants. Regular monitoring and assessment are crucial to understanding the extent of contamination and implementing effective mitigation strategies. Adsorption using activated carbon (AC), multi-walled carbon nanotubes (MWCNTs), carbon quantum dots (CQDs), and graphene/graphene oxide (G and GO) is a common technique for trapping BTEX from the air [10-13]. Biofiltration uses microorganisms to break down VOCs into less harmful byproducts. Biofilters are often filled with organic materials or microorganisms that promote biodegradation. Photocatalytic materials, such as titanium dioxide, can be used to break down VOCs under the influence of UV light [14-16]. Ozone (O_3) can oxidize and decompose VOCs, and O3 generators can treat air in industrial settings [17]. Microorganisms, such as bacteria and fungi, can biodegrade organic pollutants in water. Membrane technologies can selectively remove VOCs from water, including reverse osmosis and nanofiltration [18]. Advanced Oxidation Processes (AOPs), such as UV/H_2O_2 and UV/O3, generate highly reactive species that can oxidize and break down VOCs in water [14-16]. Human metabolic processes can naturally transform and eliminate certain VOCs [19]. Medical interventions, such as chelation therapy or specific medications, may be employed in acute exposure to certain VOCs. The effectiveness of different treatment methods depends on the specific VOCs involved, their concentrations, and the environmental or physiological context. Ongoing research focuses on improving existing technologies, exploring new materials, and developing innovative approaches to enhance VOC removal in the air or heavy metal from water samples [20-23]. Heavy metals (Pb, Hg, Cd, Cr, As, etc) can be mentioned among other dangerous environmental pollutants. The impact of heavy metals on water, air, and human health and the role of nanotechnology in their removal are important considerations. Nanotechnology holds promise for efficient and targeted removal of metals in water samples [24-28]. Acknowledging the potential risks associated with nanomaterials and ensuring responsible and sustainable implementation in environmental remediation is crucial. Regular monitoring, research, and advancements in nanotechnology will contribute to developing effective and safe strategies for heavy metal removal. Heavy metals can contaminate drinking water sources and harm aquatic ecosystems. Ingesting water contaminated with heavy metals can lead to gastrointestinal issues, cancer, and long-term health problems [29-32]. Human exposure to heavy metals, elements with high atomic weights known as heavy metals (Pb, Hg, Cd, Cr, and As), are also ongoing toxicological scenarios [23]. The impact of heavy metals on the quality of water and air, human health, and the role of nanotechnology in their removal are important considerations [23]. Biomagnification leads to the buildup of heavy metals in aquatic organisms, leading to increased concentrations in the food chain [33]. Heavy metals may contribute to particulate matter and affect air quality. Inhalation of heavy metals such as mercury, manganese, chromium, lead, cadmium, and vanadium can lead to respiratory and health problems Such as lung damage, cardiovascular effects, and cancer. Certain heavy metals can accumulate in the kidneys and liver, causing organ damage [34]. Lead and mercury exposure can impact the nervous system, leading to developmental issues in children. Engineered nanoparticles, such as nanoscale zero-valent iron, are removed from heavy metals through adsorption, precipitation, or reduction processes [35]. Nanotechnology-based filtration systems with nanoscale pores can selectively remove heavy metal ions from water. Nanomaterials with functionalized surfaces can enhance their affinity for specific heavy metals [25-27]. Nanomaterials like titanium dioxide nanoparticles can be employed in photocatalytic processes to degrade BTEX in air [14-16]. The potential toxicity of nanomaterials themselves is a concern and requires careful evaluation. The transport of nanoparticles in the environment needs consideration to prevent unintended consequences. Regulations and standards for using nanomaterials in water and air treatment must be established to ensure safety. Radioactive pollution in water and air refers to the release and presence of radioactive substances that can contaminate these environmental mediums [36,37]. The sources of radioactive pollutants include nuclear power plants, industrial facilities, medical institutions, and incidents such as nuclear accidents. The impact of radioactive pollution can be severe due to the potential health hazards associated with exposure to ionizing radiation. Radioactive substances can accumulate in aquatic organisms, leading to potential biomagnification in the food chain. Ingesting water contaminated with radioactive substances can lead to internal exposure and Increased risk of cancer, genetic mutations, and other long-term health effects. Radioactive particles released into the air can disperse large distances, affecting local and distant populations. Many radioactive isotopes have long half-lives, leading to persistent contamination. Radioactive metals can contaminate water and air through various pathways, leading to environmental and health concerns. These radioactive elements in water and air can result from natural sources, industrial activities, nuclear accidents, or improper disposal of nuclear waste [38,39]. Microplastics, small plastic particles less than 5 mm in size, can act as carriers for various pollutants, including heavy metals and VOCs. Microplastics are isolated from the sample matrix using filtration, density separation, or solvent extraction methods. Identification of microplastics is often done using microscopy techniques. Digestion breaks down the plastic matrix and releases any heavy metals associated with microplastics [40,41]. Heavy metal analysis is typically performed using techniques such as Inductively Coupled Plasma Mass Spectrometry (ICP-MS) or Atomic Absorption Spectroscopy (AAS). ICP-MS was widely used for its sensitivity and ability to analyze multiple elements simultaneously. AAS is used as a specific method for individual metals. Solvent extraction methods, such as Soxhlet extraction or sonication, are employed to release VOCs from Microplastics. Gas chromatography-mass spectrometry (GC-MS) is a widely used technique for analyzing VOCs in water/air samples [14-16]. After extraction, the collected VOCs can be separated and identified using GC-MS. Solid phase microextraction (SPME) is an alternative technique for directly extracting VOCs from the microplastic sample. Determining heavy metals and VOCs in water, air, and human samples typically involves a combination of sample collection, preparation, and analytical techniques [14-16]. Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) is used for multi-element analysis. Gas Chromatography-Mass Spectrometry (GC-MS) is highly effective for separating and identifying VOCs in water/air samples [42]. Gas Chromatography with Flame Ionization Detection (GC-FID) is suitable for organic complex samples [14-16].

The issue of pollution control is brought to the forefront by environmental pollution. Various technologies are utilized to minimize the release of pollutants into the environment through air pollution control, wastewater treatment, solid-waste management, hazardous waste management, and recycling. For instance, catalytic converters, filtration, nanotechnology processes, etc., ensure that pollutants are treated before being discharged into environment matrixes. Each technology is vital in a comprehensive strategy to reduce environmental pollution. The review study aims to evaluate and present applied and new analytical methods used for extracting and removing pollutants such as heavy metals, VOCs, and organic compounds based on nanoadsorbent in different matrixes by nanotechnology coupled to the analyzer.

2. Pollutants Analysis by Nanotechnology

Nanotechnology has been used in analytical chemistry for different fields, such as water and wastewater treatment, air Purification, human analysis [23], and treatment and environmental monitoring [43-45]. In summary, nanotechnology holds great potential for the extraction and removal of pollutants such as mercury in water [46], air [10-13], and human samples [23], offering innovative solutions for environmental protection and public health.

2.1. Water and Air Purification

Due to their small pore size and high surface area, nanomaterials can effectively remove many pollutants, including heavy metals, VOCs, BTEX, and bacteria. Materials, such as ionic liquids and filters, help to separate nanomaterials from the liquid phase [22, 20, 47, 48]. With the small pore size and high surface area, these materials can efficiently remove contaminants, including heavy metals, VOCs, BTEX, and bacteria [21,48]. Also, nanoparticles like iron oxide and titanium dioxide have been used to remove heavy metals and organic materials from water (adsorption). They can be functionalized to remove the pollutants [15,16,21]. Moreover, nanomaterial-based filters such as nanofibers and nanoparticles are integrated into air filters to enhance their efficiency in capturing particulate matter, allergens, and pollutants. Nanostructured materials provide a larger surface area for adsorption and filtration. In addition, Nanomaterials, such as titanium dioxide nanoparticles, exhibit photocatalytic properties. When exposed to light, they can break down pollutants like VOCs into less harmful substances [15,16].

2.2. Human and Animal Sample Analysis and Treatment

Nanotechnology based on biosensors, nanostructures, and nanomedicine can remove pollutants from the human body. Nanotechnology is used to develop highly sensitive biosensors for detecting contaminants in human samples [25, 48-53]. These biosensors can identify specific biomarkers associated with pollutant exposure, providing early detection and diagnosis of related health issues. Also, nano adsorbents, ionic liquids, and ligands can be used for heavy metal extraction in human and fish samples [54-57]. Nanoparticles such as functionalized SBA-15 can remove heavy metals from the different matrices [58-60].

2.3. Environmental Monitoring

Nanoparticles and nanostructures can monitor the movement of environmental pollutants and remove them [61-63]. This helps in understanding the pathways and sources of pollution, leading to better pollution management strategies. Despite the numerous advantages, using nanotechnology in environmental applications raises concerns about the potential toxicity of specific nanomaterials and their long-term environmental impact. Therefore, ongoing research focuses on developing safe and sustainable nanomaterials for environmental remediation.

2.4. Nanoadsorbents

Nanoadsorbents such as metallic nanoparticles (CdS NPs), G, GO, AC, amine-functionalized bimodal mesoporous silica nanoparticles (NH2-UVM7), and carbon nanotubes (CNTs) are materials at the nanoscale that can adsorb or attach pollutants, in their environment [24, 27, 64-68]. These nanomaterials are designed to have high surface areas and unique properties that make them effective in adsorbing various contaminants. The choice of nanoadsorbent depends on the specific pollutants targeted, the environmental conditions, and the desired application. Ongoing research is exploring new nanomaterials and optimizing existing ones to improve efficiency and address potential environmental and safety concerns. The following section lists various types of nanoabsorbents.

2.4.1. Carbon Nanotubes (CNTs)

The CNTs have tube structures of carbon atoms with HSA and high adsorption capacity. There are different types of carbon nanotubes based on their structure, namely Single-Walled Carbon Nanotubes (SWCNTs) and MWCNTs. The critical difference lies in the number of layers of carbon atoms that make up the tube structure. CNTs such as MWCNTs and SWCNTs can absorb heavy metals, organic pollutants, and gases. They may be functionalized with metal oxides, organic compounds, and ionic liquids or coated with other nanoparticles. The versatile properties of CNTs make them attractive for various applications across different industries, including electronics, materials science, energy, and medicine. However, challenges related to production scalability, purification, and cost still need to be addressed for widespread commercial adoption. Ongoing research continues to explore new applications and improve the manufacturing processes of CNTs. SWCNTs exhibit unique electronic properties, with either metallic or semiconducting behavior, depending on the specific rolling angle and chirality [23, 42]. Due to their biocompatibility, they have different applications in electronics (transistors, sensors), energy storage, drug delivery, and imaging. MWCNTs have multiple layers of graphene concentrically arranged to form a tube with excellent mechanical and thermal properties and can exhibit metallic or semiconducting behavior. MWCNTs reinforce materials, such as polymers and composites, enhancing their mechanical strength [44, 45]. MWCNTs, similar to SWCNTs, are explored for applications in supercapacitors and batteries and can be used as a catalyst and biosensor support due to their high surface area (SA). There are several methods for synthesizing carbon nanotubes (CNTs), and the choice of method depends on the desired properties, application, and production scale (Fig.1). These methods are: A) Chemical Vapor Deposition (CVD) involves the catalytic decomposition of hydrocarbons at elevated temperatures. By the CVD method, a substrate with a catalyst (usually iron, nickel, or cobalt nanoparticles) is exposed to a hydrocarbon gas (such as methane or ethylene) at high temperatures (typically 600-1000°C). B) Arc discharge is an effective method for producing MWCNTs (MWCNTs) on a relatively large scale. A high-current electric arc is generated between two graphite electrodes in an inert atmosphere. Carbon

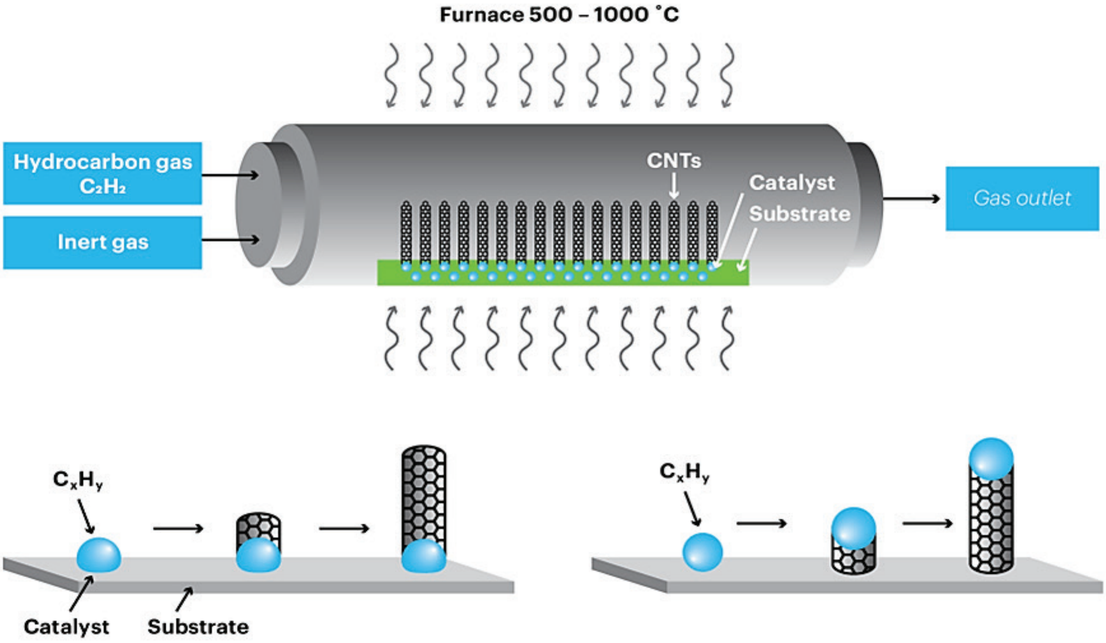

Fig.1. The standard chemical vapor deposition (CVD) method for synthesizing carbon nanotubes

is vaporized from one electrode and condenses to form nanotubes on the other electrode. This method can produce a significant quantity of CNTs, but the process tends to yield a mixture of SWCNTs and MWCNTs. C) Laser ablation, a high-power laser beam, is used to ablate a carbon target in the presence of a reactive gas. Laser ablation can produce high-quality SWCNTs with fewer impurities. Other methods, such as the Chemical Reduction of Carbon Sources, High-Pressure Carbon Monoxide (HiPCO) Method, and Template-Assisted Growth, were used for CNT synthesis [23, 42,44, 45].

2.4.2.Graphene and Graphene Oxide(G/GO):

Graphene oxide is known for its high surface area, offering numerous active sites for chemical reactions and a strong attraction to organic and inorganic pollutants. Its versatility in removing many substances, including pharmaceuticals, personal care products, and endocrine-disrupting chemicals, makes it a valuable tool in water treatment. Additionally, graphene oxide can be tailored to target specific contaminants, enhancing its effectiveness. Its cost-effectiveness, abundance, stability under harsh conditions, and efficiency in water treatment systems make it a promising solution for addressing emerging contaminants. Single layers of carbon atoms are designed as hexagonal lattices based on HSA, good electrical conductivity, and strong adsorption capabilities [10]. G and GO were used to remove heavy metals, organic pollutants, and dyes from water. Graphene synthesis by various methods: mechanical exfoliation (Scotch Tape Method) involves using adhesive tape to peel off layers of graphene from a highly ordered pyrolytic graphite (HOPG) crystal; CVD is a popular method for large-scale graphene synthesis, liquid-phase exfoliation involves exfoliating graphene from graphite in a liquid medium, and in chemical reduction of GO. The GO can be reduced to rGO, near pristine graphene [14,16]. Graphene oxide is often used as an intermediate precursor for graphene production. It is synthesized through the oxidation of graphite (Fig.2). The Hummers' and the Brodie methods are two common approaches. G and graphene oxide have similar applications to CNTs. Functional groups on GO enhance their interactions with target molecules, making them useful in sensors. These applications demonstrate the versatility of graphene and graphene oxide in various fields, and ongoing research continues to explore new possibilities and improve production methods [64,68].

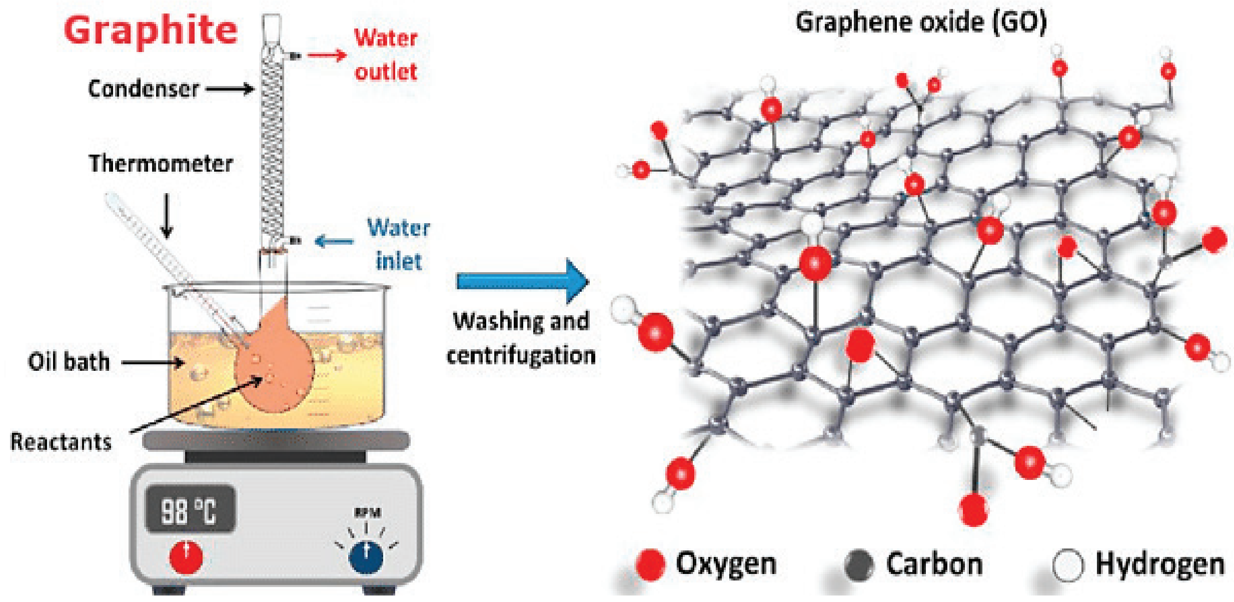

Fig.2. Synthesized GO based on reactants in an oil bath in a condenser by the oxidation of graphite [14.15]

2.4.3.Metal Oxide Nanoparticles

Metal oxide nanoparticles (MONPs) are metal precursors and are utilized in various fields such as physics, chemistry, and material sciences. These nanoparticles can form various oxide compounds with diverse structural geometries and electronic properties, exhibiting insulators, semiconductors, or metal characteristics. MONPs possess unique optoelectrical features due to their localized surface plasmon resonance characteristics, particularly in noble metals like Ag, Au, and Cu. The synthesis of metal nanoparticles, including their size and shape, is crucial in modern materials research. Metal nanoparticles, especially gold nanoparticles, are commonly used in SEM analysis to enhance electronic conductivity and produce high-quality images. Nanosized metal oxides, such as manganese, iron, titanium oxides, and others, have high removal capacity and selectivity for heavy metals, making them promising adsorbents. The effectiveness of MONPs in antibacterial activities and dye removal from wastewater depends on factors like morphology, size, and aggregation, emphasizing the importance of synthesis techniques focusing on these aspects. MONPs such as titanium dioxide (TiO_2), bismuth oxide (Bi_2O_3), and iron oxide (Fe_2O_3, Fe_3O_4) were used for the removal of pollutants in various matrixes. The properties of metal oxide nanoparticles are photocatalytic activity, high surface area, and magnetic properties for iron/copper oxide. This material removes pollutants through photocatalytic degradation, extraction, and adsorption [14-16].

2.4.4.Clay-Based Nanomaterials

Clay-based nanomaterials such as Montmorillonite and kaolinite have high surface area, porosity, and ion exchange capacity. Clay-based nanomaterials are used for adsorption of heavy metals, organic pollutants, and dyes [69-71].

2.4.5. Metal-Organic Frameworks (MOFs), Nanocomposites and Biopolymer

MOFs are porous materials with metal ions that can connect to organic linkers. MOFs have a high surface area, tunable structure, and large pore volume used for the adsorption of gases and the removal of organic pollutants and heavy metals. Nanocomposites are a category of nanomaterials in which nano-sized components are incorporated into a ceramic, metal, or polymer matrix, leading to the emergence of novel characteristics. These materials are engineered to demonstrate properties that surpass, and in some cases significantly surpass, the combined capabilities of their elements. These nanomaterials offer enhanced oxidation resistance, high efficiency, and energy-saving benefits. Nanocomposites combine nanomaterials with polymers or other materials with Synergistic effects, improved stability, and enhanced adsorption properties for removing various pollutants in water and air. Biopolymer-based nanomaterials such as chitosan nanoparticles and cellulose nanocrystals were adsorbed by heavy metals and aromatic compounds. Biopolymer-based nanomaterials have unique properties that are biodegradable, renewable, and modified for specific adsorption [72-74].

2.4.6. Silica-Based Nanomaterials and Nano-Zero Valent Iron (nZVI)

Silica nanoparticles with high surface area, tunable surface chemistry, and stability were used to adsorb heavy metals, organic pollutants, and dyes. Silica-based nanoparticles (SNPs) have biomedical applications such as nanocarriers and biomodulators. SNPs, or silica nanoparticles, can be used as carriers for delivering therapeutics [27,58,59,64]. Scientists have worked on modifying their physical properties, such as particle size, shape, and structure, to improve their effectiveness. However, due to the inert nature of the silica framework, conventional SNPs are typically limited to being used as carriers for targeted delivery and controlled release. Nano-Zero Valent Iron (nZVI), based on reductive capability and a high surface area, was used to remove heavy metals and degrade chlorinated compounds [35]. Figure 3 shows three synthetic ways for mesoporous silica nanoparticles.

2.4.7. Magnetic Nanoparticles and Bimetallic Nanoparticles

Magnetite, formed from a combination of Fe(II) and Fe(III) salts through co-precipitation in alkaline conditions, possesses distinctive superparamagnetic properties and absorption capabilities. Its utilization not only enables the absorption and elimination of pollutants but also allows for its modification as a reusable heterogeneous catalyst for converting

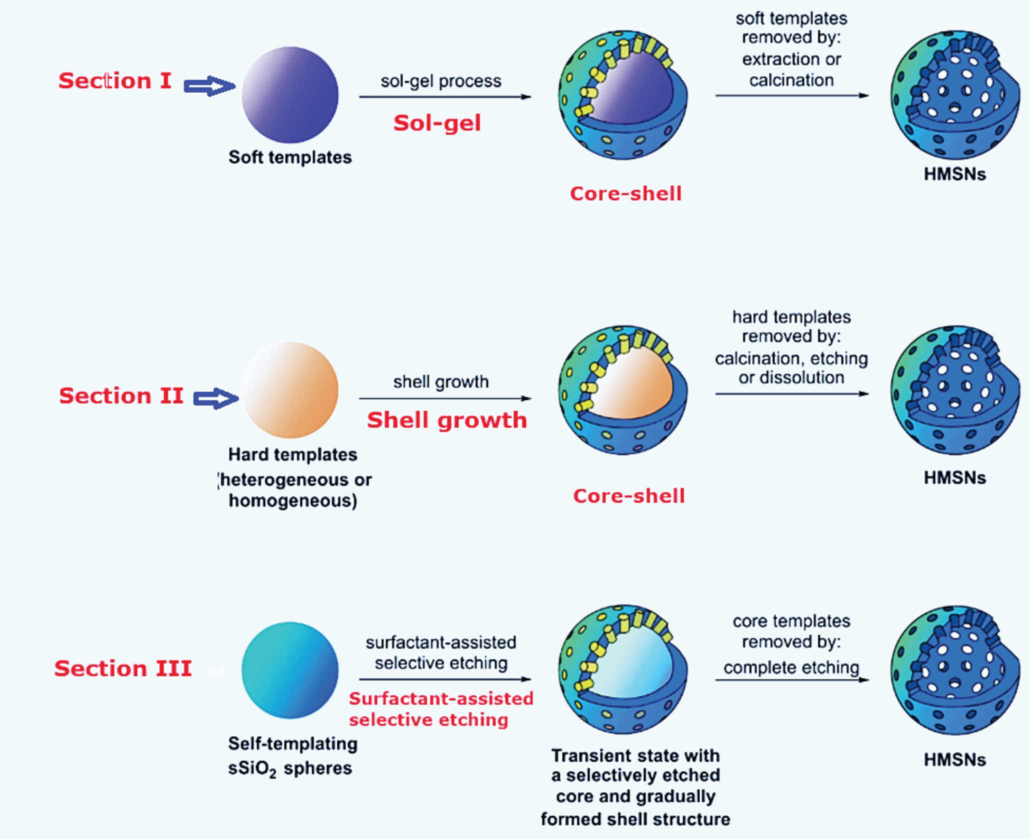

Fig. 3. Section I is the soft-templating method, Section II is the hard-templating method, and Section III shows the process of self-templating fabrication of HMSNs [64]

contaminants into valuable by-products. Magnetic nanomaterials have extensive applications in water treatment due to their easy separability, reusability, non-toxic nature, and controllable size and shape. Magnetite nanoparticles are crucial in various fields, such as magnetics, electronics, biomedical sciences, and sensor technology. These nanoparticles serve as effective adsorbents in water treatment, facilitating easy separation through high magnetism. Functionalized magnetite composites are commonly employed for metal separation and water purification, offering improved outcomes and cost efficiency. Composite nanoparticles reduce the required dosage and enhance the efficiency of functionalized particles. Magnetite (Fe3O4) nanoparticles based on magnetic properties for easy separation and high surface area were used for targeted removal of contaminants with an external magnetic field [36,44,54,61]. Bimetallic nanoparticles, such as palladium-silver nanoparticles, based on the synergistic effects of two different metals, can effectively remove chlorinated hydrocarbons.

3. Methods for extraction and removal of pollutants by nanotechnology

Extraction and removal techniques for pollutants from different sources (including water, air, soil, and biological samples) encompass a variety of methods [26,28,75,76,77]. Nanotechnology-based nanoadsorbent was used for the extraction/removal of pollutants in different matrixes [78-82]. Recently, researchers have presented some common extraction and removal methods, including both traditional and nanotechnology. Filtration involves the physical separation of solid particles from a liquid or gas using a porous membrane such as nano filters or membranes, CNTs [23, 42,44, 45], nanographene (NG)[64,68], NGO[14,16], Metal-organic frameworks: MOFs [72-74], Mesoporous silica nanoparticles: MSNs) with nanoscale pores (< 100 nm) [27, 58-60] for enhanced filtration efficiency. Adsorption is the adherence of molecules or particles to the surface of a solid or liquid material. The adsorption process may be followed by nanotechnology based on nanoadsorbents, such as CNTs (MWCNTs and SWCNTs) [42,44], NG-silica [64], NGO [68], metal oxide nanoparticles (MO-NPs), functionalized carbon structure (ionic liquid-CNTs, Fe_3O_4-GO) to enhance adsorption capacity [36,44,54,61]. Researchers reported the Unified Bioaccessibility Method (UBM) and NiCo2O4@ ZnCo2O4 nanomaterial to help determine pollutants [83-86]. The formation of solid particles from dissolved substances in a liquid phase causes precipitation and removal of pollutants. Some nanoparticles, such as zinc oxide (ZnO), Fe3O4, or MO-NPs, are used to induce or catalyze precipitation reactions to increase removal efficiency. In this removal, the pH is critical for precipitation such as $Zn\ (OH)_2$. Ion Exchange causes the replacement of ions in a solution with other ions. The ion-exchange properties of nanostructures are used to target the removal of specific ions in solution at optimized pH. On the other hand, coagulation and flocculation of aggregate particles are created by adding reagents to the solution by nano adsorbents. By bioremediation, microorganisms or their metabolic products are used to break down or transform pollutants. Also, Plants are used to absorb, accumulate, or transform contaminants by phytoremediation and incorporation of nanoparticles to enhance plant uptake and remediation efficiency. In addition, the oxidizing or reducing agents cause the breakdown of pollutants by chemical oxidation/reduction with nanocatalysts, such as zero-valent iron nanoparticles (ZVINPs), for enhanced oxidation or reduction reactions [35]. Occasionally, light (UV, Vis) and a catalyst act as photocatalysis to initiate chemical reactions that decompose pollutants (Titanium dioxide nanoparticles TiO_2, Bi_2O_3 enhanced degradation of pollutants) [14-16]. Sorption is a process of adsorption and absorption of contaminants onto a solid material. In extraction-based solvents, the solvents or extraction agents are used to separate pollutants from a matrix by designing nanocarriers to extract or encapsulate contaminants efficiently. Also, membranes with specific pore sizes are used to separate components based on size or other properties. The different methods and nano adsorbents can be employed individually or in combination, depending on the pollutants and the characteristics of the matrix. Nanotechnology provides innovative solutions to enhance the effectiveness of these techniques and address challenges associated with traditional methods. Pollutants are substances of the environment that cause harm or discomfort to living organisms. These pollutants can be classified into various categories based on their origin, physical state, and environmental impact. Some common types of pollutants are classified as air, soil, water pollutants (heavy metals), radioactive pollution, microplastics, greenhouse gases, and VOCs. For air pollutants, particulate matter (PM), such as fine particles and droplets, is suspended in the air, including dust [76], soot, and aerosols. Nitrogen oxides (NOx), SO2, CO, and O3 are also air pollutants. Water pollutants include heavy metals (lead, mercury, and cadmium) [26-28, 46], nutrients, pathogens (bacteria, viruses, and parasites), and chemical contaminants (Pesticides, herbicides, pharmaceuticals, industrial chemicals, and other synthetic compounds). Heavy Metals, pesticides and herbicides (chemicals used in agriculture to control pests and weeds), and industrial wastes are soil pollutions. Radioactive substances are elements or isotopes that emit radiation, often produced as byproducts of nuclear processes or present in certain minerals. Microplastics are tiny plastic particles (less than 5 mm) that can accumulate in water and soil [40,41]. Greenhouse gases such as CO_2, CH4, and N2O are another source of air pollution. VOCs (VOCs) can evaporate into the air, and other organic materials, such as methyl orange or blue pollution, can be analyzed in water and biological matrixes [71,69]. The impact of pollutants on the environment and human health varies, and efforts are made to monitor, regulate, and reduce their emissions through environmental management and conservation practices. Nanotechnology methods have been developed for the extraction/ removal, and adsorption of pollutants from different sources such as water, air, agriculture, and human samples. Hosseini et al. proposed a new method that utilizes a nanomagnetic composite material called Fe3O4@4-PhMT-GO, which is modified with graphene oxide (Fig.4).

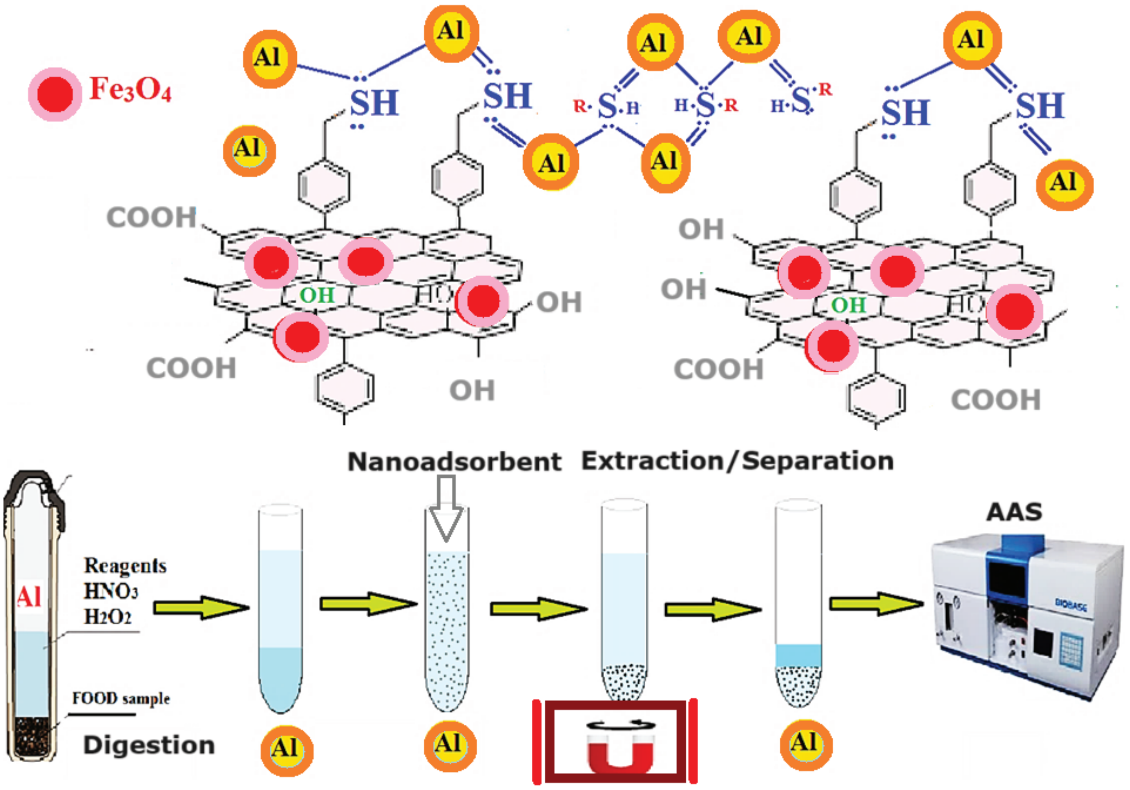

Fig.4. Determination of aluminum (Al) from wastewater, food, and vegetable samples by the Fe3O4@4-PhMT-GO adsorbent [87]

This method is used for the extraction of aluminum (Al) from wastewater, food, and vegetable samples. The extraction process is carried out by a microwave system coupled to magnetic micro SPE. The result showed the working and linear ranges between 0.005 to 5 and 1.6 mg L^{-1}, respectively; the LOD and an enrichment factor were obtained at 1.5 μg L^{-1} and 50, respectively (RSD= %2.5). The organic, inorganic, and total aluminum were achieved in water samples through the MDM-μ-SPE procedure. [87]. Faghihi et al. used ionic liquids on glassy balls (ILs/GBs) to remove toluene from the air. Toluene vapor was absorbed on 0.2 g of ionic liquids at room temperature and desorbed from the adsorbent at 110 °C before being determined by GC-FID. The removal of toluene [Ph3P-(CH2)3-SO3H][TOS] was obtained at more than 95%, and the adsorption mechanism of toluene was dependent on π–π interaction between toluene and ionic liquids.

The ILs-GBs with chemical adsorption between tri-phenyl / imidazolium/ pyridinium and toluene vapor have been ascribed to π–π /n–π EDA interaction as compared to ILs without aliphatic chains [20, 88]. Golbabaei et al. used a new procedure for the speciation of Hg in human samples, which was ionic liquid-liquid extraction with CV-AAS. By procedure, 1 mL of Ammonium pyrrolidin-dithiocarbamat (1%, APDC) solution was mixed with 10 mL of human blood (pH 7) with 0.2 g of IL. Mercury was complexed as Hg-APDC in IL. Total Hg was determined after the blood sample was put in the microwave [89]. In another study, cadmium in blood samples was extracted/separated with magnetic -N-thiol-functionalized graphene oxide (M-NT-GO) by USA-DM-μ-SPE before measured by ET-AAS. The linear range, LOD, and PF were achieved at 0.03–1.5 μg L^{-1}, 0.01 μg $L^{-1,}$ and less than 5%, respectively (MRSD<2 %). The adsorption capacities of M-NT-GO were 185.3 mg g^{-1} for cadmium. They used 20 mg of the M-NT-GO at pH 6 [90]. Karamzadeh et al. reported a new adsorbent CysSB/MetSB@MWCNTs for Ni/Co determination in human samples by ultrasound-assisted coupled to dispersive ionic liquid-suspension SPME. The adsorbent was suspended in IL and added to the blood samples. Co/Ni (II) extracted by IL-CysSB @MWCNTs in a conical tube and determined by ET-AAS. The LOD and EF of MWCNTs adsorbent were achieved (30 ng L^{-1}; 20 ng L^{-1}) and 50 for Ni and Co ions, respectively. The adsorption capacity for Ni and Co was 226.7 and 193.3 mg g^{-1}, respectively [91]. Esmaeili et al. showed that MWCNTs@ [Apmim][PF_6] adsorbent could be specified the mercury (Hg^{2+}, O-Hg) in water samples (pH 8.5) by UAS-D-SPE before determined by CV-AAS. The linear range and LOD for inorganic/organic mercury were 20–3500 ng L^{-1} and 5-6 ng L^{-1}, respectively (RSD<2%). The capacity absorption of MWCNTs@[Apmim][PF_6] for Hg(II) ions was achieved at 186.2 mg g^{-1} [92]. Also, Esmaeili et al. used the TSIL functionalized on MWCNTs for styrene extraction in water samples by cyclic conjugation-micro-solid phase extraction procedure (CC-μSPE). The linear range (LR) and LOD were 0.001–6.5 mg L^{-1} and 260 ng L^{-1}, respectively (RSD%=1.45). The absorption capacities of MWCNTs@[Hemim][BF_4] was 183.2 mg g^{-1} [93]. Mousavi et al. presented a magnetic carbon nanotube-nickel hybrid (MNi-CNT) for extracting four tyrosine kinase inhibitors (imatinib, sunitinib, erlotinib,and nilotinib).Thelimits of quantification for imatinib, sunitinib, erlotinib, and nilotinib were obtained at 0.7, 1.7, 0.6, and 1.0 μg L^{-1}, respectively(RSD<4.5%) [94]. Faghihi et al. used the B_2O_3-NG/NGO adsorbent for removing xylene from the air by UV radiation-catalectic degradation-adsorption procedure (UV-PCDA)/ GC-MS. The capacity adsorption of BONPs-NG/NGO achieved 223 mg g^{-1} [14] (Fig. 5). Also, Faghihi et al. used ionic liquids to remove toluene vapor from the air [20]. Marek Trojanowicz reported that the flow methods used in the analysis are based on nanotechnology. Nanotechnology affects analytical instrumentation and methods [95].

Rakhtshah et al used 2,3-dimercapto-1-propanol functionalized on MWCNTs for lead speciation in different matrixes by dispersive ionic liquid-

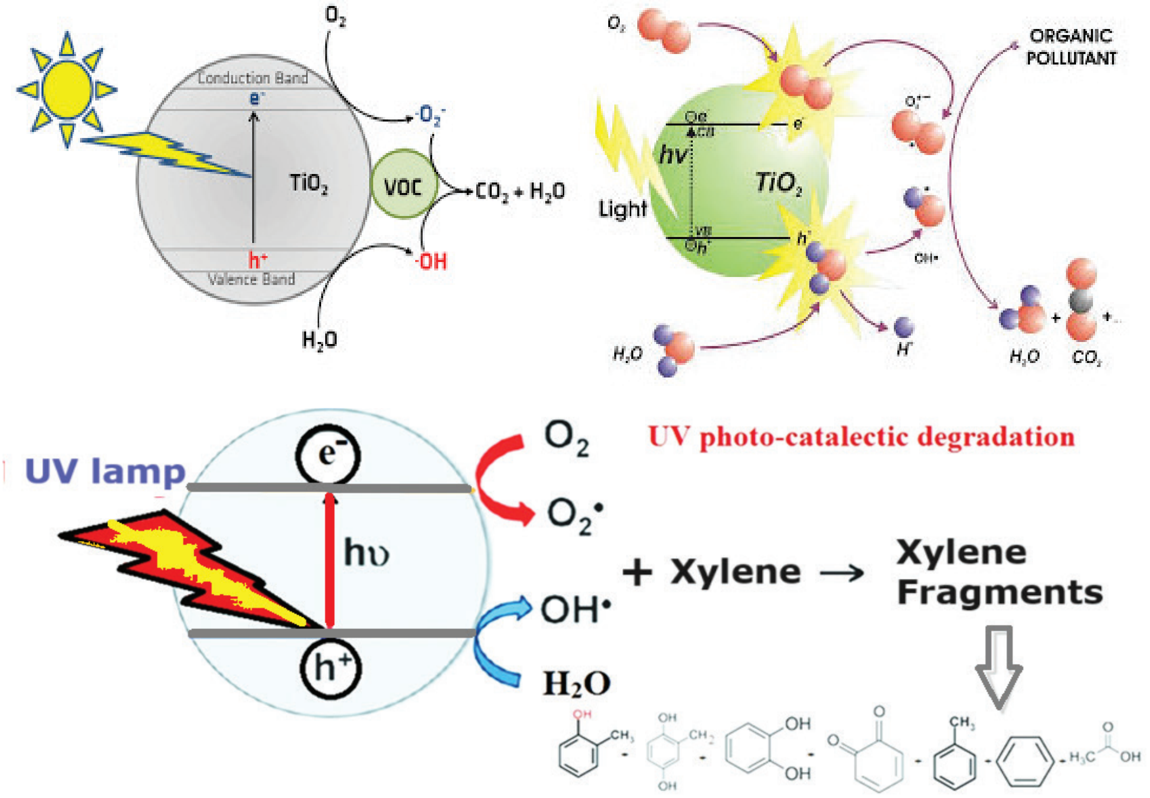

Fig.5. UV photo-catalectic degradation for removal of xylene and BTEX from the air [14]

suspension SPE. They showed that the linear range and adsorption capacity were reported at 9.5–480 μg L^{-1} and 191.6 mg g^{-1}, respectively (RSD < 5%) [96]. Mirzahosseini et al analyzed the heavy metals (vanadium, cobalt, nickel, arsenic, and mercury) in water, soil, and vegetables by GIS. They used GIS to display the distribution of heavy metals at various locations. [97]. Soylak et al can determine the concentrations of the different elements in the children's cosmetic products in Turkey.

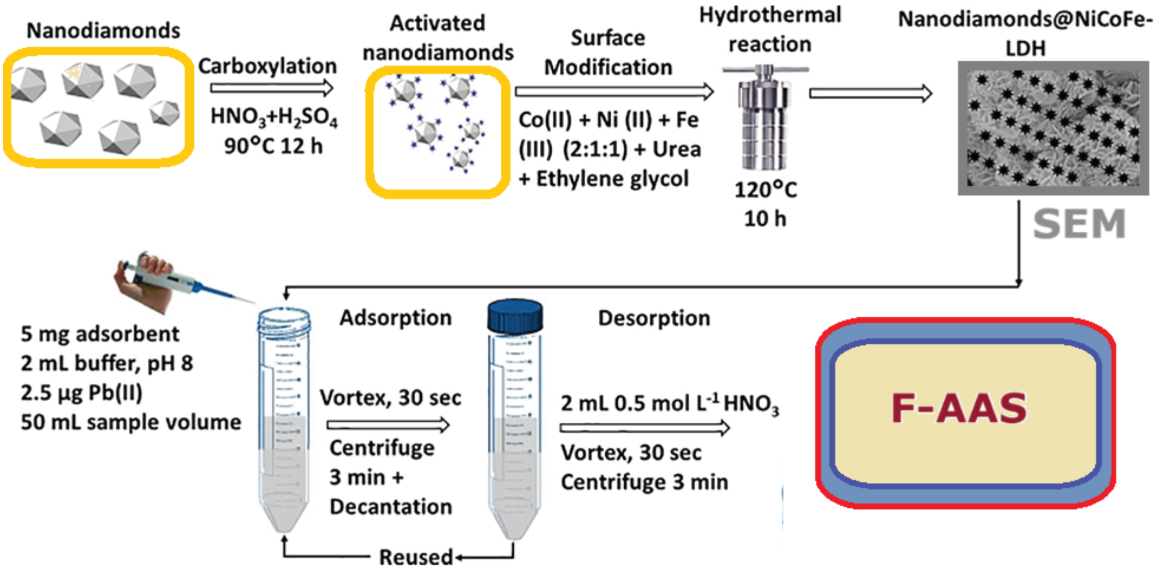

Fig.6. The nanodiamonds@NiCoFe-LDH for separation of lead based on SPME before determination by F-AAS [78,99]

The ICP-MS technique was used to analyze the children's cosmetic products after processing with the microwave digestion system.[98]. Due to Figure 6, Soylak et al. used a new SPME based on nanodiamonds@NiCoFe-LDH for extraction of Pb(II) before determination by F-AAS[78, 99]. The LOD was obtained as 0.62 ng mL^{-1}. Also, Soylak et al. studied MCOFs as an adsorbent in the magnetic SPE method in environmental analysis for pesticides, VOCs, drugs, heavy metal ions, and other environmental contaminants (Fig.7) [100]. Mustafa Tuzen et al. demonstrated a fast hydrophobic deep eutectic solvent (HDES) coupled DLLME for analyzing benzoic acid in food samples using UV-vis spectrophotometry. The LOD of 12 μg L^{-1} and linear range of 40–1000 μg L^{-1} were obtained [80]. Also, they used copolymer-gadolinium oxide nanoparticles (Gd_2O_3) for the extraction of total arsenic [81]. The enrichment factor and LOD for arsenic were obtained at 128 and 0.02 μg L^{-1}, respectively. In addition, many methods were recently presented for the extraction/separation/removal of VOCs, BTEX, dyes, drugs, amino acids, and aerosol pollution in water and air samples [12,16, 21, 69, 93, 101-110]. Zhang et al. showed the adsorption of heavy metals by modified biochar in water samples [111]. Golbabaei et al. used micro-columns of amin-mesoporous silica nanoparticles (MSN) to remove and specify chromium in water samples[112]. Eskandari et al reported a DLLME method with ionic liquids for determination/ speciation of chromium in human samples and also, and they reported a cloud point assisted based-DLLME by isopropyl 2-[(isopropoxycarbothiolyl) disulfanyl [56,113]. Mousavi et al used acetylcysteine for chromium speciation in human samples by D-LLME [114]. A review of the determination of famotidine drug using the chemiluminescence method presented by Al-Samarrai [115]. Advanced analysis in green analytical chemistry studied by Alsayadi et al. [116]. According to Jaber Ibrahim, Ultra trace elements in the human blood of radiography workers were evaluated by GF-AAS [117]. Rouhollahi and Osanloo used nanotechnology (AgNPS) for mercury removal from the air [118-120]. Golbabaei et al.

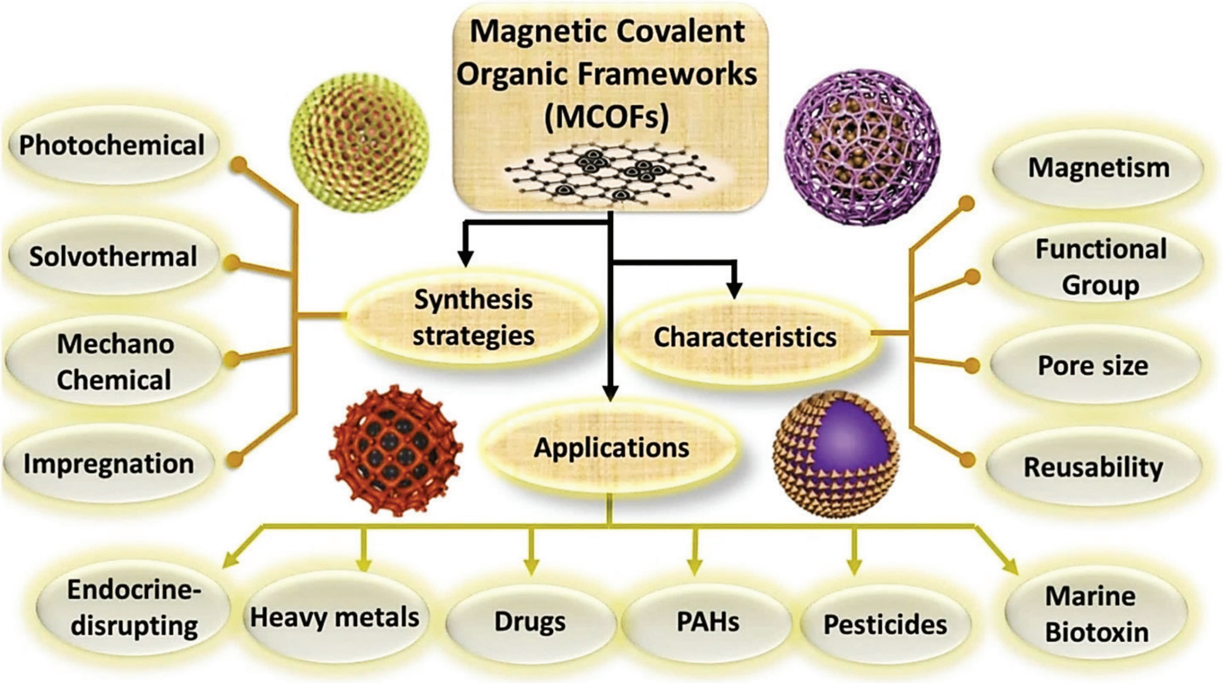

Fig.7. Magnetic covalent organic frameworks (MCOFs) as an adsorbent in the magnetic SPE method in environmental analysis for pesticides, VOCs, drugs, and heavy metal ions [100]

used nano-palladium embedded in MSN for mercury removal from air [121]. Also, Many adsorbents such as bismuth oxide (Bi_2O_3) nanoparticles, Cu-doped ZnO nanotubes, hydrogel-based spin-column, amine-functionalized-MSN, IL-modified nano-graphene, functionalized MWCNTs, and Ni-Fe modified $Cu(OH)_2$ needle were used for extraction/removal/determination pollutant in different matrixes by analytical techniques[122-128]. In addition, various analytical methods were used for the evaluation of neurobehavioral symptoms for Mn and Hg exposure, heavy metal determination in multiple sclerosis patients, and heavy metal concentration in environmental samples and human workers [129-132]. In all analytical techniques to remove pollutants based on nanotechnology, the physical and chemical properties, basic chemistry, and metal complexation are important factors that must be considered and studied [133-136].

The high oxidation of iron complexes plays a critical role in catalytic processes and analytical chemistry or the removal of pollutants. Martin Keilwerth et al used high-valent Fe(VI) nitride as a reactive, super-oxidized, heptavalent Fe(VII) nitride [137] which is shown in Figure 8**.**

In another study, UV/O_3 is used for the degradation of VOCs and the removal efficiency of toluene [138] (Fig.9). The removal of Cu^{2+}, Ni^{2+}, and Zn^{2+} in water by the ZnO-modified date pits (MDP) was studied. The adsorption capacity for Cu^{2+}, Ni^{2+}, and Zn^{2+} based on MDP were achieved at 82.4, 71.9, and 66.3 mg g^{-1}, respectively [139]. Also, the heavy metals (Fe^{3+}, Mn^{2+}, and Ni^{2+}) were removed from the Lanthanides solution by graphene oxide-citrate (GO-C) adsorbent. The Langmuir model yielded the best adsorption isotherm. The adsorption capacity for Fe^{3+}, Mn^{2+}, and Ni^{2+} was achieved at 530, 223, and 174 mg g^{-1} [140].

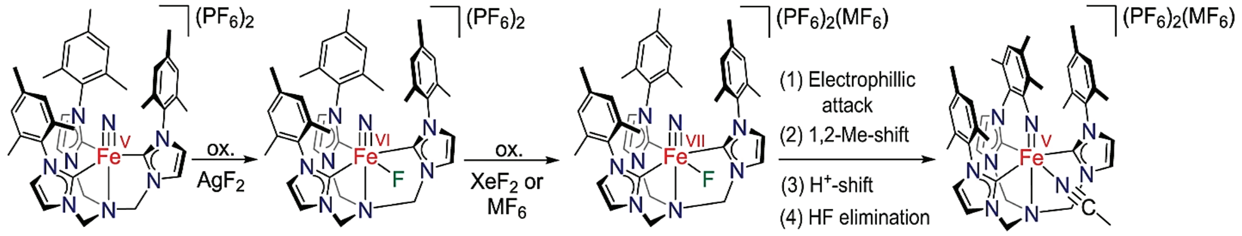

Fig.8. Oxidation of the Fe(VI) nitride to Fe(VII) nitride (MF6 with M = Mo, Re), therefore, rearranges intramolecularly and causes a high-valent, unusual Fe(V) imide[137].

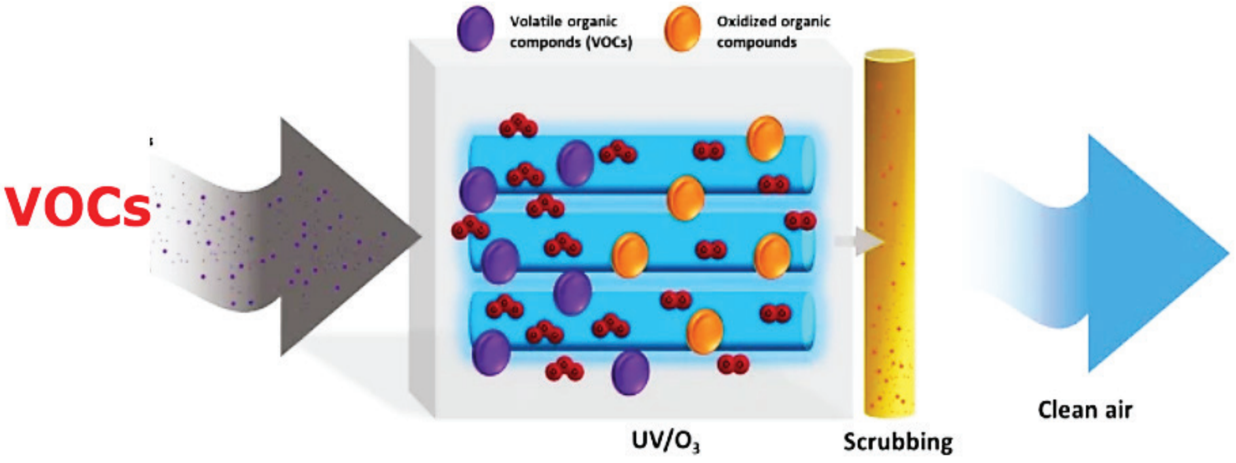

Fig.9. The UV-assisted ozonation (UV/O_3) is used for the degradation of VOCs [140]

Vinicius Diniz et al. reported that the organic contaminant (caffeine) could be adsorbed by the porous sulfur polymers (PSPs) [141]. Due to the procedure, 100 mg of the PSPs was added to caffeine solutions and stirred (300 rpm). At various times, samples were passed through a filter, and the caffeine concentrations were measured using a UV–vis spectrometer at 273 nm (Fig.10). Also, formaldehyde and methyl tert-butyl ether in environmental and human samples were analyzed by headspace coupled to gas chromatography-mass spectrometry (HS-GC-MS) [142].

4. Comparing different adsorbents for the removal of pollutants

To remove VOCs and BTEX from different matrixes such as air and water samples kinds of adsorbents such as nano-graphene modified by ionic liquid, Polyethylene glycol 200 (PEG200) and ionic liquids (ILs), Nano-activated carbons (NACs), IL:[BMIM][PF6], bismuth oxide-fullerene nanoparticles (B_2O_3NPs), ionic liquids were pasted on micro glass balls, copper oxide, Functionally magnetic multi-walled nanotubes (MWCNTs), Fe_3O_4 nanoparticles in zeolitic imidazolate frameworks, hierarchical mordenite framework inverted (MFI) type nano zeolite including Si-MFI, Pd/CeO_2 nanoparticles, Na-P1 zeolite, Platinized titanium dioxide, MnOx/TiO_2/AC, Alkylation-modified pistachio shell-based biochar, B_2O_3NPs-NG/NGO, Modified MIL-101(Cr) using any modulator, Butyl-3-methyl imidazolium hexafluorophosphate, Al-MFI, Zeolite, Spinel-type Mesoporous $ZnFe_2O_4$ Nanoparticles, N@S-TiO_2 Nanotubes, M-IANC, mesoporous carbon–ZrO_2 nanocomposite, hollow Co/N doped carbon frameworks, NiAl/Fe-Al Nanoparticles, 1-benzyl imidazole pasted on TiO_2@ NGO Nanostructure, and C_6H_5- [NH_2HIM] [PF_6] @ MWCNTs were compared together in Table 1 and different absorption capacities and recovery were obtained [88,11,14,15, 20, 21,106, 143-162]. Also, different methods for determination heavy metald was compared as Table 2.

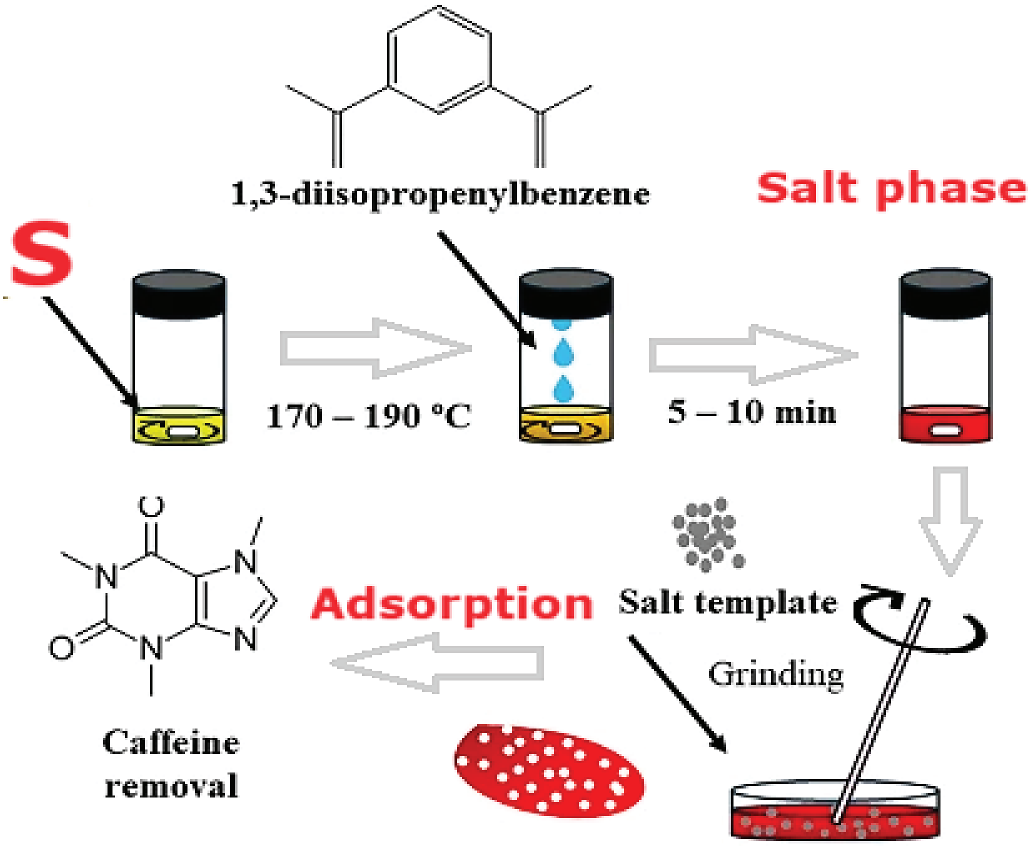

Fig.10. The v removal based on the porous sulphur polymers (PSPs) before determination by UV–vis spectrometer [141]

Table 1. Comparing different adsorbents for VOC/BTEX removal from the air and water by various methods

ollutant	Sorbents	Techniques	Sample	Recovery (%) / AC	Ref.
Toluene	Nano-graphene modified by ionic liquid (NG-IL)	Adsorption	Air	90-95% 126 mg g^{-1}	[88]
Benzene	PEG200- Ionic liquid	Absorption	Water	R:85.4 T R:87.2% B 114.97 mg g^{-1}	[143]
Xylene	Nano-activated carbons (NACs)	Adsorption/GC-FID	Air	116.8-205.2 mg g^{-1} 76.55%	[11]
Toluene	[BMIM][PF6]	Absorption	Milk	5.16 mg g^{-1} 82.85%	[144]
Toluene	bismuth oxide-fullerene nanoparticles	UV-photocatalytic oxidation method (UV-PCOM /GC-FID	Air	212 mg g^{-1} and more than 95%	[21]
Toluene	ionic liquids were pasted on micro glass balls	Adsorption	Air	218.4 mg g^{-1} More than 90%	[20]
Toluene benzene	CuO-NPs	Extraction	Water	Benzene: 100.24 mg g^{-1} Toluene: 111.31 mg g^{-1} R: 92.5%	[145]
BTEX	Functionally magnetic multi-walled nanotubes (MWCNTs)	Adsorption	water	Toluene = 63.34 mg g^{-1} EB = 249.44 mg g^{-1} Xylene = 227.05 mg g^{-1}	[146]
Toluene benzene	Fe3O4 nanoparticles in zeolitic imidazolate frameworks	Adsorption GC-FID	Water	Toluene: 133.1 mg g^{-1} Benzene: 137.3 mg g^{-1} R Benzene: 94.4% R Toluene: 93.1%	[147]
Toluene	MFI (Si-MFI, Al-MFI, Ti-MFI)	Adsorption	Gas	58 mg g–1	[148]
Toluene	0.5%(Pd/CeO_2) Nanoparticles	Adsorption	Air	R Toluene: 90 %	[149]
BTEX	Na-P1 zeolite ($Na_6Al_6Si_6O_{32}$. $12H_2O$)	Adsorption GC-FID	Water	Benzene:0.032 mg g^{-1} Toluene: 0.050 mg g^{-1} AC o-X: 0.147 mg g^{-1} AC p-X: 0.129 mg g^{-1}	[150]
VOCs	Platinized titanium dioxide	Photocatalytic Degradation	Air	Toluene: 68.2% Benzene: 46.5% Xylene: 95.9%	[151]
Toluene	MnOx/TiO_2/AC	MDELs photo-degradation	Gas	94%	[152]
BTEX	AMPSB	Absorption	water	Toluene: 169.9 mg g^{-1} Ethyl acetate: 96.77 mg g^{-1}	[153]

Xylene	BONPs-NG/NGO	UV-PCDA	Air	134.6 -223 mg g^{-1} 38.8 % and 98.7 %	[14]
BTEX	Modified MIL-101(Cr) using any modulator	Adsorption	Gas	90.14 %	[154]
Toluene	Al-MFI	Adsorption	Wet gas	58 mg g^{-1}	[155]
Toluene	Zeolite	Absorption	Water	AC: 95 mg g-1 R= 92.6	[156]
Toluene	Spinel-type Mesoporous $ZnFe_2O_4$ Nanoparticles	Photocatalytic Degradation	Gas	R Toluene: 60 %	[157]
VOCs	N@S-TiO_2 Nanotubes	Photocatalytic Degradation	Gas	94%	[158]
Toluene, Benzene	M-IANC	Adsorption	Ambient	Benzene: 18.22 mg g^{-1} Toluene:82.1 mg g^{-1}	[159]
BTEX	MC- $ZrO_{2:}$	Headspace Mode-Solid-Phase Microextraction/ GC-FID	Water	R: 93% R^2> 0.996	[160]
Toluene	Hollow Co/N co-doped carbon frameworks	Photocatalytic Degradation	Gas	Toluene: 78.2%	[161]
Toluene	NiAl/Fe-Al Nanoparticles	Hybrid Plasma-Catalysis	Vapor	Toluene 96%	[162]
Toluene	BIM-TiO_2@NGO Nanostructure	Adsorption/ Semi degradation/Desorption process	Air	99% 234.5 mg g^{-1}	[15]
BTEX	Phe and [NH_2HIM] [PF_6] @ MWCNTs	Absorption/Extraction	Water Milk	AC Benzene: 286.6 mg g-1 AC EB: 248.5 mg g-1 AC Toluene: 234.6 mg g-1 AC xylene: 195.6 mg g-1 R> 95%	[106]

AC: Absorption capacity, **R**: Recovery, **SA**: Surface area, **BTX**: Benzene, Toluene, Xylene
MWCNTs: magnetic multi-walled carbon nanotube
MFI: Mordenite Framework Inverted
Si-MFI: Hierarchical Mordenite Framework Inverted (MFI) type nano zeolite including Si-MFI
BIM:1-benzyl imidazole
PCD: Photocatalytic destruction
UV-PCDA: UV photo-catalectic degradation-adsorption procedure
MnOx/TiO2/AC: Catalyst prepared by the solvent-deficient method
MWCNT: Magnetic multi-walled carbon nanotube
AC: Activated carbon
PEG200-ILs: Polyethylene glycol 200 (PEG200) and ionic liquids (ILs)
complex absorbents composed of [EMIM][Cl], [BMIM][Cl],[HMIM][Cl], [BMIM][BF4], [BMIM][PF6], [BMIM][NTF2], and PEG200
[Bmim][PF6]: Butyl-3-methyl imidazolium hexafluorophosphate
MC- ZrO2: mesoporous carbon–ZrO2 nanocomposite
AMPSB: Alkylation-modified pistachio shell-based biochar
BTX: Benzene, Toluene, Xylene

Table 2. Comparing the different procedure for analysis heavy metals in water and food samples

Method Extraction	Adsorbent	Technique	Matrix	Metal	*LOD	*PF/ EF	*LR	RSD%	Ref.
MDMSPE/ SFODME	M - $ZnFe_2O_4$ NT	ET-AAS	Tap water	Mn (II), Mn (VII)	<0.1	200	----	4.8	[163]
DIL-S-µSPE	MWCNTs@DMP	F-AAS	water,	Pb (II)	3.2	10.4	9.5–480	5.0	[96]
USA-DILT-µ-SPE	N-acetylcysteine on chloro-functionalized MWCNTs	F AAS	Water/ Food	Mn (VII)	0.18	96.8	0.6–38.7	4.6	[164]
SPME	PSCOVC	F AAS	water	Mn, Zn	0.2,7.9	145	0.15–250	2.1-3.4	[165]
SPE	Graphene oxide		Water	Pb	2.1	102.5	7–260	4.1	[68]
SPE	graphene	F-AAS	Water	Pb	0.61	50	10-600	3.25	[166]
Co-precipitation	------	F AAS	Water/ Food	Mn (II), Mn (VII)	0.75	50	0.1-3.0	<7.0	[167]
US-D-µ-SPE	NH_2-UVM-7	AT-F AAS	Water	Mn (II), Mn (VII)	------	102.3, 98.8	0.5-48.7	2.3, 2.8	[168]
USA-D-µSPE	Graphene- Clinoptilolite Hybrid	ETAAS	Water	Cd- Pb	0.07	20	0.24-10.3	3.4	[169]
USA-CP-MSPE	Amine functionalized silica aerogel	ETAAS	Water	Pb	0.01	102	0.04–1.4	3.25	[170]
MDM- µ-SPE	Fe_3O_4@4-PhMT-GO	ET-AAS	Water/ Food	Al (III)	0.012	48.8	0.05–2.5	2.8	[87]
DES-LPME	HPhImNaph	F AAS	Water	Mn (II)	0.52	92.9	3-100	2.7	[171]
IL- DLLME/ SFS	IL-Oxine	SF	Water	A l(III)	0.05	100	0.06–15	1.7	[172]
SPE	XAD-1180-PV	AAS	Water	Al(III)	0.021	-----	5-10	4.32	[173]

*__EF/PF__: Enrichment factor/ preconcentration factor, **LOD:** Limit of detection, µgL^{-1}, **LR:** Linear Range, µgL^{-1}

PSCOVC: Poly(styrene)-co-2-vinylpyridine copolymer

AT-FAAS: Atom trapping-flame atomic absorption spectrometry

SF: spectrofluorometry

MSM: Multivariate statistical methods.

HPhImNaph: 3-[[(2-hydroxyphenyl) imino]methyl]-2-naphthalenol

DES-LPME: Deep eutectic solvent-based liquid phase microextraction

DLLME: Dispersive liquid-liquid microextraction

PAN: 1-(2-Pyridylazo)-2-naphthol

NGO-PTT: Graphene oxide (GO) packed column and 1-Phenyl-3-(2-phenylmethyl) thiourea (PPT)

SPE: Solid phase extraction (SPE)

ESM: Eggshell membrane

DMSPE: Dispersive micro solid-phase extraction

MDMSPE: Magnetic dispersive micro-solid phase extraction

SFODME: solidified floating organic drop microextraction

M -$ZnFe_2O_4$ NT: Magnetic $ZnFe_2O_4$ nanotubes

ET-AAS: graphite furnace atomic absorption spectrometer

USA-CP-MSPE: Ultrasound-assisted cloud point-micro solid phase extraction

5. Conclusions

The application of nanotechnology for removing and extracting pollutants from various matrices helps simple, efficient methods for determining, separating, and preconcentrating pollutants. Due to the statistical results, the nanomaterials such as MWCNTs, SWCNTs, NG/NGO, AC, MSN, and MOFs had more efficiency in removing pollutants in different environmental samples. The previous research showed that ionic liquids (ILs) and TSILs can separate nanoparticles and nano adsorbents from liquid phased with high recovery. Also, ILs passed on nanosorbents could absorb VOCs and heavy metals from air, water, and human biological samples, respectively. By harnessing the unique properties of nanoparticles, such as high surface area and reactivity, significant advancements have been made in enhancing pollutant removal efficiencies (more than 95%) and minimizing environmental impacts. Using nanoadsorbent highlights nanotechnology's versatility in removing heavy metals or VOCs from air, water, soil, or human samples. Statistical results in analytical methods such as LOD, LOQ, linear range, absorption capacity, RSD%, enrichment factor, and recovery (%) reveal compelling evidence of the effectiveness of nanomaterials in achieving pollutant removal targets, thereby contributing to sustainable environmental management strategies.

6. Acknowledgments

The authors are very thankful to the management of the Analytical Chemistry Department of Environmental Health Engineering, Zabol, Iran, and the Department of Chemistry, Faculty of Science, Kerman branch, Islamic Azad University for supporting this study.

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