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Recent Advances and Developments in Nanoparticles/ Nanocomposites as Nanoadsorbent for Adsorptive Removal of Lead in Wastewater: A Review

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Abstract

Wastewater and or water contamination due to Lead is of significant occupational and environmental concern because of the possibility of Lead to enter the food chain. There are numerous adsorbent used in adsorption of Lead in wastewater. This includes agricultural biomass, industrial sludge as well as activated carbon prepared from these materials. Recently, nanoparticles and nanocomposites have been synthesized and applied as nanoadsorbent for Lead removal from solution. This review highlights synthesis, characterization and application of nanoadsorbents for Lead adsorption in wastewater.

Keywords: Adsorption; Nanoadsorbent; Nanoparticles/Nanocomposites; Lead; Wastewater

Abbreviations: WHO: World Health Organisation; SEM: Scanning Electron Microscopy; FTIR: Fourier Transform Infra-Red Spectroscopy; TEM: Transmission Electron Microscopy; IR: Infrared; NIR: Near-Infrared; UV: Ultraviolet-Visible; TGA: Thermal Gravimetric Analysis; XRD: X-Ray Diffraction; CMC: Carboxy Methyl Chitosan; ED: Eleocharis Dulcis.

Introduction

Lead contamination is becoming a serious issue of concern around the world due to the increase in the use and processing to meet the needs of the rapidly growing population. In general, all components of the environments such as soil (land), water, and air are affected by Lead pollution. Land (soil) contamination due to Lead comes from the following sources and activities such as industrial activities, mine tailings, disposal of high metal wastes, leaded gasoline and paints, land application of fertilisers, animal manures, sewage sludge, pesticides, wastewater irrigation, coal combustion residues and spillage of petrochemicals lead to soil contamination by heavy metals. There are different ways through which Lead present risks to humans, animals, plants and ecosystems as a whole. For example; direct ingestion, absorption by plants, food chains, consumption of contaminated water and alteration of soil pH, porosity, colour and its natural chemistry which in turn impact on the soil quality [1,2]. Industrialization and urbanisation are two main sources of water contamination due Lead. Lead is transported by runoff from industries, municipalities and urban areas. And the Lead end up accumulating in the soil and sediments of water bodies [3]. Lead can be found in traces in water sources and still be very toxic and impose serious health problems to humans and other ecosystems. Thus, the contamination of water by Lead actually affects all living organisms. Air pollution due to Lead has their sources from natural processes and anthropogenic activities. Natural processes release particulate matters containing Lead into air such as dust storms, soil erosion, volcanic eruptions and rock weathering, while anthropogenic activities are more industrial and transportation related [4,5].

Severe damages to the nervous system, kidney, reproductive system, brain, liver cause illness or death has been reported due to Lead poisoning. And severe exposure to lead has been connected with stillbirths, abortion, sterility and neonatal death [2-9]. Thus, the permissible limit recommended by the World Health Organisation (WHO) is (3-10 µg/L) in drinking water [10]. Therefore removal of lead in effluent and water remains crucial. Different methods are employed for the treatment of industrial effluents containing Lead. These important methods are chemical precipitation, ion exchange, electrodialysis and adsorption etc. But Adsorption technique being very economical, simple, versatile and effective has been widely preferred for the removal of Lead from aqueous environment [11-30].

Nanotechnology can be used to monitor water quality in real time and even remove pathogens (diseases such as cholera) and inorganic pollutants (toxic heavy metals)as well as organic pollutants from water, making it possible for even the most remote communities to have safe, clean drinking water. This can be achieved with the aid of various nanoadsorbents obtained from different nanoparticles and nanocomposites. Therefore, this article gives a brief overview on application of nanoparticles/ nanobiocomposites for the removal of Lead from aqueous environment.

Adsorption

Adsorption is the adhesion of ions, or molecules, atoms, from a liquid, gas or dissolved solids to a surface. The solids that are used to adsorb gases or dissolved substances are called adsorbents and the adsorbed molecules are referred as the adsorbate. Adsorption creates a film of adsorbate on the surface of adsorbent. It is a surface phenomenon that depends upon specific surface area, number of site available, porosity of the adsorbent and numerous interactions types. No formation of harmful substances is associated with adsorption process [31-36].

Nanoadsorbent Fabrication

There are two main approaches to synthesize nanoadsorbent. One is top-down approach and another is the bottom-up approach. All other classifications fall on these two approaches. The descriptions of these approaches are as followed.

Top-Down Approach

As the name suggests, the top-down approach means from top (larger) to bottom (smaller). This approach is similar to making a statue made of stone. As in making of a statue, a bulk or big piece of stone is taken, similarly in top-down approach; a bulk piece of material is taken. Then carving and cutting is done until desired shape is achieved. Examples include chemical etching, grinding, ball milling, thermal/laser ablation and sputtering [37].

Bottom-Up Approach

As the name suggests, the bottom-up approach means from bottom (smaller) to top or up(larger). In this technique, a nanometric structure is taken then using methods of assembly or self assembly, a mechanism is developed which is larger than where it is started. Chemical/Electrochemical, precipitation, vapour deposition, atomic/molecular condensation, sol gel processes, spray pyrolysis, laser pyrolysisand aerosol pyrolysis as well as green synthesis(such as using bacteria, fungi, plant extracts etc) are examples of botto-up approach [33].

Nanoadsorbent Characterization

The most common techniques used in characterization of nanoadsorbent based on these studies are Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM), X-Ray Diffraction, Fourier transform infra-red spectroscopy (FTIR), Ultraviolet-visible spectroscopy and Thermal gravimetric analysis [31-54].

Fourier Transform Infra-Red (FTIR)

Fourier Transform Infrared (FTIR) spectroscopy is a powerful tool for identifying types of chemical bonds in a molecule by producing an infrared absorption spectrum that is like a molecular fingerprint. Infrared (IR) spectroscopy is one of the most common spectroscopic techniques used by organic and inorganic chemists. Simply, it is the absorption measurement of different IR frequencies by a sample positioned in the path of an IR beam. The main goal of IR spectroscopic analysis is to determine the chemical functional groups in the sample. Different functional groups absorb characteristic frequencies of IR radiation. Using various sampling accessories, IR spectrometers can accept a wide range of sample types such as gases, liquids, and solids. Thus, IR spectroscopy is an important and popular tool for structural elucidation and compound identification [39].

Ultraviolet-Visible (UV-Vis) Spectroscopy

Ultraviolet-visible spectroscopy or ultraviolet-visible spectrophotometry (UV-vis or UV/vis) refers to absorption spectroscopy in the ultraviolet-visible spectral region. This means it uses light in the visible and adjacent (near-UV and near-infrared (NIR)) ranges. The absorption in the visible range directly affects the perceived color of the chemicals involved. In this region of the electromagnetic spectrum, molecules undergo electronic transitions [39].

Thermal Gravimetric Analysis (TGA)

Thermo gravimetric analysis or thermal gravimetric analysis (TGA) is a method of thermal analysis in which changes in physical and chemical properties of materials are measured as a function of increasing temperature (with constant heating rate), or as a function of time (with constant temperature and/or constant mass loss). TGA can provide information about physical phenomena, such as second-order phase transitions, including vaporization, sublimation, absorption, adsorption, and desorption. Likewise, TGA can provide information about chemical phenomena including chemisorptions, desolvation (especially dehydration), decomposition, and solid-gas reactions (e.g., oxidation or reduction). TGA is commonly used to determine selected characteristics of materials that exhibit either mass loss or gain due to decomposition, oxidation, or loss of volatiles (such as moisture) [39].

X-Ray Diffraction (XRD)

The discovery of X-rays in 1895 enabled scientists to probe crystalline structure at the atomic level. X-ray diffraction has been in use in two main areas, for the fingerprint characterization of crystalline materials and the determination of their structure. Each crystalline solid has its unique characteristic X-ray powder pattern which may be used as a "fingerprint" for its identification. Once the material has been identified, X-ray crystallography may be used to determine its structure, i.e. how the atoms pack together in the crystalline state and what the inter atomic distance and angle are etc. X-ray diffraction is one of the most important characterization tools used in solid state chemistry and materials science. We can determine the size and the shape of the unit cell for any compound most easily using X-ray diffraction [39].

Transmission Electron Microscopy (TEM)

TEM is a powerful and unique technique for structure characterization. The most important application of TEM is the atomic-resolution real-space imaging of nanoparticles. TEM is unique in identifying and quantifying the chemical and electronic structure of individual nanocrystals. Electron energy-loss spectroscopy analysis of the solid-state effects and mapping the valence states are even more attractive. In situ TEM is demonstrated for characterizing and measuring the thermodynamic, electric, and mechanical properties of individual nanostructures, from which the structure-property relationship can be registered with a specific nanoparticle/structure [39].

Scanning Electron Microscopy (SEM)

The Scanning Electron Microscope images of the surface of the sample under measurement by scanning it with a high-energy beam of electrons. SEM gives topographical as well as chemical composition [39].

Application of Nanoadsorbent for Lead Adsorption in Wastewater

Table 1 provides the summery of numerous nanoadsorbents used for removal of Lead in wastewater. The nanoadsorbent is used either as a nanoparticle or its combination to another nanoparticle or other materials (to give nanocomposite). Montmorillonite-silica nanocomposite was synthesized and found to have higher percentage removal of 99.99% and adsorption capacity of 132.802 mg/g [40]. The removal efficiency of Lead by some iron base nanoadsorbent was widely investigated by different authors. Magnetite –Dowex 50WX4 (Mag-Dow) nanocomposite was synthesized, characterized and tested for heavy metal ions (Cr (VI), Ni^{2+},Cu^{2+},Cd^{2+} and Pb^{2+}) removal. Transmission Electron Microscopy (TEM) results showed the formation of nanoparticles of size ranging from 2-10 nm. Adsorption experiments in batch mode were conducted using the developed nanocomposite. Different factors affecting the adsorption process like reaction time, initial metals concentration, pH and adsorbent dose were investigated to optimize the operation conditions for the composite nanoparticles .The adsorption capacity of the composite was found to increase by time and adsorption attains equilibrium in 30 min. The desorption efficiency for different metals used was found to be 96 % of the prepared adsorbent suggest that the prepared composite is as an effective tool for removal of Lead [18]. Vazquez-Olmos, et al. [26] reported the adsorption of Pb(II) from aqueous solution using MFe_2O_4 nanoferrites (M = Co, Ni, and Zn). Nanoferrite samples were prepared via the mechanochemical method and were characterized by X-ray powder diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), micro-Raman, and vibrating sample magnetometry (VSM). XRD analysis confrms the formation of pure single phases of cubic ferrites with average crystallite sizes of 23.8, 19.4, and 19.2 nm for $CoFe_2O_4$, $NiFe_2O_4$, and $ZnFe_2O_4$, respectively. Only $NiFe_2O_4$ and $ZnFe_2O_4$ samples show super paramagnetic behaviour at room temperature, whereas $CoFe_2O_4$ is ferromagnetic. Kinetics and isotherm adsorption studies for adsorption of Pb(II) were carried out. A pseudo-second-order kinetic describes the sorption behaviour. The experimental data of the isotherms were well fitted to the Langmuir isotherm model. The maximum adsorption capacity of Pb(II) on the nanoferrites was found to be 20.58, 17.76, and 9.34 $mg \cdot g^{-1}$ for M = Co, Ni, and Zn, respectively. Shiralipour, et al. [22] studied the adsorption of Lead (Pb) by zero-valent iron nanoparticle in contaminated water. Four samples, each from different water sources like Well water (Shushtar, Iran), Karoon River (Ahvaz, Iran), Caspian Sea (northern Iran) and Persian Gulf (southern Iran) were collected. The elapsed time for quantitative removal of Pb ions was two minutes. The adsorption of Pb ions on ZVINPs was well followed by the Langmuir model. The maximum adsorption amounts of Pb ions on ZVINPs were 96.5 mg/g. In other report, Magnetic chitosan (CS) and carboxymethylchitosan (CMC) Nanocomposites have been synthesized by a simple one-step chemical co-precipitation method. The nanoparticles were assessed for the removal of Pb^{2+} ions from aqueous solution. Kinetic and thermodynamic models were used to describe and understand the adsorption process of the ions onto the nanomaterial. The interactions between the ions and the biopolymer-based composites are reversible, which means that the nanoparticles can be regenerated in weakly acidic or EDTA containing solution without losing their activity and stability for water cleanup applications. The maximum adsorption capacity of Magnetic chitosan (CS) and carboxymethylchitosan (CMC) Nanocomposites were found to be 141 and 243 mg/g respectively [27]. Giraldo, et al. [30] reported that Fe_3O_4 magnetic nanoparticles were synthesized by co-precipitation method. The structural characterization showed an average nanoparticle size of 8 nm. The synthesized Fe_3O_4 nanoparticles were tested for the treatment of synthetic aqueous solutions contaminated by metal ions, i.e. Pb(II). Various factors influencing the adsorption of metal ions, e.g., pH, temperature, and contacting time were investigated to optimize the operating condition for the use of Fe_3O_4 nanoparticles as adsorbent. Pb(II) adsorption efficiency gradually increases from 75.7 % to 92.3 % when the pH increases from 2 to 7. The maximum adsorption capacity of Fe_3O_4 nanoparticles in the investigated conditions was 0.180 mmol g^{-1}. The study of biocomposite nanoparticles of *Eleocharis dulcis* (ED) as potentials biosorbent to reduce the concentration of lead (II) ion containing Sasirangan textile industry wastewater was investigated [50]. Batch experiments were carried out to considering the kinetic of biosorption of lead onto the adsorbent, evaluating the effects of lead ion equilibrium concentration, equilibrium pH, and temperature on the adsorption of lead (II). Kinetic data of lead (II) biosorption onto EDB and EDB-MH revealed that equilibrium time was reached within 2 h, and the isotherm data showed that the Langmuir maximum adsorption capacity of the EDB-M and EDB-MH at pHe of 6±0.2, room temperature were 150.43 mg/g and 180.92 mg/g, respectively [50].

Das, et al. [53] developed a simple approach for the biosynthesis of iron oxide nanoparticles (Fe_3O_4-NPs) using *Trigonella foenum-graecum* leaf extract and used it for possible removal of lead from aqueous solution and wastewater. SPR peak at 248 nm confirms the bioreduction and formation of Fe_3O_4-NPs. The shape and size of the nanoparticles were evaluated by SEM equipped with EDX, TEM, XRD. The particles were found crystalline and roughly spherical in shape with an average size range of 51.6-215.7 nm. The possible biomolecules participated in the biosynthetic reaction which was confirmed by FTIR spectrum. These nanostructured particles were used for batch adsorption study for the removal of lead ions. The effects of various physical and chemical parameters like pH, contact time, adsorbent dosage and initial concentrations on the removal of heavy metals were studied on removal efficiency. The maximum lead (II) ions removal uptake was found 93±0.13% at pH 6.0 with 0.4g of these nanoparticles within 60 min of contact time. Desorption studies indicated that the regenerated nanoparticles retained its original metal adsorption efficiency. Results showed that these regenerable iron oxide nanoparticles can be used as nano-adsorbent for removal of heavy metals from environmental waste due to its high metal uptake capacity. According to Namavari [42], Efficiency of $Ni0.5Zn0.5Fe_2O_4$ magnetic nanoparticles supported by Aloe vera shell ash in removing Pb from aqueous environments was studied. The adsorbent was characterized by several methods, including x-ray diffraction (XRD), scanning electron microscopy (SEM), and Fourier transform infrared spectroscopy (FT-IR). Then, the potential of Aloe vera shell ash-supported Ni0.5Zn0.5Fe_2O_4 magnetic nanoparticles to adsorb Pb (II) was investigated. To determine the amount of lead absorbed by this adsorbent, different pHs (2, 4, 5, and 6), adsorbent doses (0.01-0.40 g), Pb concentrations (5, 10, 20, 30, 40, 50, 60, 80, 100, 200, 300, and 600 mg/L), and exposure times (0, 5, 10, 15, 20, 30, 40, 50, and 60 minutes until reaching equilibrium) were tested using an atomic absorption spectrometer (Varian-AA240FS). Residual concentrations of Pb were read. The results show that a time of 15 minutes, pH value of 9, and adsorbent dose of 0.2 g are the optimum conditions for Pb (II) removal by this adsorption process. Increase in the initial concentration of Pb (II) from 5 to 600 mg/L decreased removal efficiency from 98.8% to 73%. The experimental data fit well into the Freundlich isotherm model (R2 = 0.989).

Haerizade, et al. [44] reported thatToxic lead ions was removed efficiently from water by a newly fabricated, magnetically recyclable, antibacterial nano-Ag/γ-Fe_2O_3@GOadsorbent, at ambient and the physiological pH=7. The adsorption depends on the adsorbent dosage, initial Pb(II)concentration, pH and the contact time. The optimum removal efficiency of the leadion is found to be 93.1% with a dosage rate of 20 mg/L, in 40 minutes, at pH 5 (to 14). Equilibrium data fits well with the Langmuir and Freundlich models with a maximum adsorption capacity of 90.91 mg/g of Pb(II) per 20 mg/L of Ag/γ-Fe2O3@GO. The removal/uptake mechanism involves interaction between Pb(II) and the oxide/hydroxyl layer around Ag/γ-Fe_2O_3@rGO, in the contaminated water medium. Moezzi, et al. [45] stated that, a reduction method in solution phase was applied to synthesize the iron nanoparticles and used in lead removal. Afterwards, the size of the synthesized particles was confirmed by Scanning Electron Microscopy. It is worth noting that the nanoparticle dose-variations were examined in the range of 0.02-0.5mg while pH and exposure time were respectively investigated in the ranges of 3-11 and 1-40 min. Meanwhile, the removal efficiency of various concentrations of lead ions were evaluated in the range of 1-50 mg/l. The results indicated that the best removal efficiency (92.5%) occurred in the concentration range of 1 to 40 mg/l for a dose of 0.1 mg nanoparticles. By increasing concentration of lead ions to 50 mg/l, the optimum dose was achieved in 0.2 mg. Improved removal was observed with increasing exposure time up to 10 minutes while no improvement was recorded for exposure times of 20 minutes or longer. The results confirmed the effectiveness of synthesized iron nanoparticles in removing lead ions from aquatic solution.

Other nanoparticles apart from iron based nanoparticles were also used in removal of Lead in solution. Thus, Composite based on eucalyptus leaf and polyaniline (EL-PANi) was prepared by chemical polymerization method. It showed that the function groups belonging to polyaniline and eucalyptus leaf were found through IR analysis and the nanostructure of composite was explained by SEM images. The adsorption of Pb^{2+} was carried out onto composite in aqueous solution via varying pH, contact time, and its initial concentration. The experimental adsorption data fitted well into Freundlich adsorption isotherm model (R2 ~ 0.99). The adsorption process followed pseudo-second order kinetic with R2 ~ 1. The maximum adsorption capacity qmax of Pb2+ onto that composite was 172.41 mg/g by Langmuir equation and Freundlich constant KF was 53.75 mg/g by Freundlich one [20]. Poursani, et al. [21] reported that nano-TiO2 particles were synthesized by sol-gel method. The synthesized nanoparticles were characterized by Fourier Transform Infrared (FT-IR), X-ray diffraction (XRD), Transmission electron microscope (TEM) and Brunauer-Emmett-Teller (BET). The results showed that the average size of TiO_2 nanoparticles and their specific surface area were 21.1 nanometer and 55.35 m^2/gr, respectively. The effects of several variables such as adsorbent weight, pH and contact time on lead ions adsorption were studied in batch experiments and finally the optimum conditions for lead ions adsorption by synthesized nano-TiO_2 were obtained. The results showed that the synthesized nano TiO_2 had a good capacity to adsorb lead ion. The kinetic data were described by pseudo-first and second-order models. Freundlich and Langmuir isotherm models were used for the analysis of equilibrium data, and results showed that the Langmuir model was suitable for describing the equilibrium data of lead ion adsorption by nano TiO_2. Using the Langmuir isotherm, the maximum sorption capacity of Pb^{2+} was estimated to be 7.41 (mg/g) at 25°C. Dargahi, et al. [29] investigated the efficiency of magnesium oxide nanoparticles (MON) *in vitro* for the removal of lead (II) and chromium (VI) from aqueous environments. The effects of various parameters such as contact time (15 to 280 min), pH (3, 5, 7 and 9), the initial concentration of lead/chromium (10, 20, 30. 40 and 50 mg/L), absorbent dose (0.3, 0.5 and 0.8 g/L), and shaking speed (150 to 350 rpm) was investigated. The parameters were optimized by varying one parameter at a time and keeping other parameters constant. The maximum removal efficiency of

MON for lead (II) and chromium (VI) was achieved at contact time 280 min, pH 9, initial concentration of lead/chromium 10 mg/L, adsorbent dose 0.8 g/L, and shaking speed 250 rpm. The results also indicated that MON convert the Pb^{2+} to Pb^0 and Cr^{6+} to Cr^{3+} during the removal process. The adsorption of lead (II) and chromium (VI) follows the Langmuir isotherms, therefore the adsorption was of a physical nature. Zadeh, et al. [16] reported that Al_2O_3-SiO_2 nanoparticle was an effective adsorbent for removal of Lead in solution. Thus in the study, Al_2O_3-SiO_2 nanoparticle by the weight ratio 50:50 of Al_2O_3/SiO_2 was studied to obtain an effective adsorbent for the removal of Pb(II)ion from aqueous solution. In this research, a simple ,economic and environment-friendly method has been presented for the preparation of $Al_2O_{3}.SiO_2$ nanoparticle via sol-gel method. The structure of prepared nanoparticle was characterized by FTIR, BET, SEM, XRD and EDX. The SEM analysis shows that the average size of the particles is about 40 nm and BET analyzer data shows that the average pore size and surface area of the material are 4.9522 nm and 163.58 m^2/g respectively. Various factors influence the adsorption of Pb(II) ion such as contact time, the amount of adsorbent and pH value of the solutions which were investigated by batch experiments. The adsorption was fast; nearly 98% of Pb (II) could be removed within 10 min. The equilibrium data was applied to Langmuir, Freundlich, Tempkin, isotherm models. Adsorption isotherm fitted well by Freundlich model. The maximum adsorption capacity is 37.03 mg/g at pH = 8.0. Kinetics data revealed that the overall adsorption process followed pseudo-second-order. This study proves that Al_2O_3-SiO_2 nanoparticle was an effective adsorbent for removal of Pb(II) ion from aqueous solutions.

Therefore, from Table 1 the optimum conditions for Lead removal using various nanoadsorbents were found in the following ranges; 76-99.99% removal, 7-976 mg/g adsorption capacity, pH of 2-11, 0.001-2.5 g adsorbent and 1-280 minutes. These suggest that nanoadsorbents are promising adsorbents for environmental protection application especially for Lead remediation.

Nanoadsorbent type	**Adsorbent, g**	**pH**	**Time, min.**	**Adsorption capacity, mg/g**	**% Rem.**	**Ref.**
PVK-GO Polymer nanocomposite	0.001	7	90	887.98	97	[8]
Poly(amidoamine)-graft-poly(methyl acrylate) magnetic NC	0.01	6-May	30	310		[9]
CAZn, activated carbon	0.2	6	80	72.62		[10]
CAH, activated carbon			80	58.62		
CAK, activated carbon			100	12.16		
CuO,	0.1	3.5	30		84.162	[11]
Fe_3O_4 nanoparticles					88.028	
Magnetite–Dowex 50WX4 nanocomposite	0.5	6.5	30	380	97	[14]
eucalyptus leaf and polyaniline (EL-PANi) composite	0.1	6	10	172.41	95	[16]
TiO_2 nanoparticle	0.2	6	240	7.41	90	[17]
Zero-valent iron nanoparticles	0.2	2	2	96.5	99	[18]
NC-MC composite	6	6		907	76	[19]
NC-KC composite				976	85	
Chromium doped NiO nanoparticles	0.15	9	45		99.6	[20]
$CoFe_3O_4$	0.01	2	60	20.58		[22]
$NiFe_3O_4$				17.76		
$ZnFe_3O_4$				9.34		
Cs mangnitite			5	141		[23]
CMC magnetite				243		
nanoparticles						
MgO nanoparticle	0.8	9	280	21.78	94.78	[25]
Fe_2O_4	0.2	7	2	0.189	92.3	[26]
Montmorillonit-silica nanocomposite	0.3	5	40	132.802	99.99	[36]

CS NP-modified MnO$_2$	2	6	3	102.5	93	[37]
Ni0.5Zn0.5Fe$_2$O$_4$ magnetic nanoparticles	0.2	2	15	47.2	98.8	[38]
Polyaniline (PANI) nanocomposites	0.4	4	120	7	90	[39]
Ag/γ-Fe2O3@GO nanocomposite	0.02	5	40	90.91	93.1	[40]
Iron nanoparticle	0.1	11	10		99	[41]
CdS nanoparticle	2	6	15	200	98	[42]
Rice straw/magnetic nanocomposites	0.13		1	19.45	96.25	[44]
Nd-TiO2/bentonite	0.3	7	15	16.94	83	[45]
Ce-TiO2/bentonite nanocomposites				17.53	80	
Eleocharis dulcis Fibers -Fe$_3$O$_4$ Nanoparticles	2.5	6	120	180.92		[46]
Nano-silversol-coated activated carbon	2.5	5.5	60	23.81	92.42	[48]

Table 1: Nanoadsorbents used for the removal of Lead in wastewater.

Conclusion

Recent advances and developments in nanoparticles/nanocomposites as nanoadsorbents have proven to be significant and powerful tool for removal of Lead in wastewater due their unique properties especially high surface area to volume ratio. In this review the following were noted;

Bottum-up synthesis was mostly used in synthesizing the nanoadsorbent than the Top-up method. In fact from this review, top-up method was used by only one researcher in synthesizing the nanoadsorbent.

Most used characterizations techniques for the nanoadsorbents includes; SEM, TEM, FTIR, XRD, TGA and Ultra-violet/visible spectroscopy.

Only batch adsorption method was used by the researchers with no report on column adsorption.

Large scale industrial wastewater treatment was not reported and therefore recommended.

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