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S Sophie Beulah
Government College of Engineering, Tirunelveli, Tamil Nadu, India

Corresponding Author:
S Sophie Beulah
Government College of Engineering, Tirunelveli, Tamil Nadu, India

Various adsorbents for the Removal of Pb(II) from wastewater

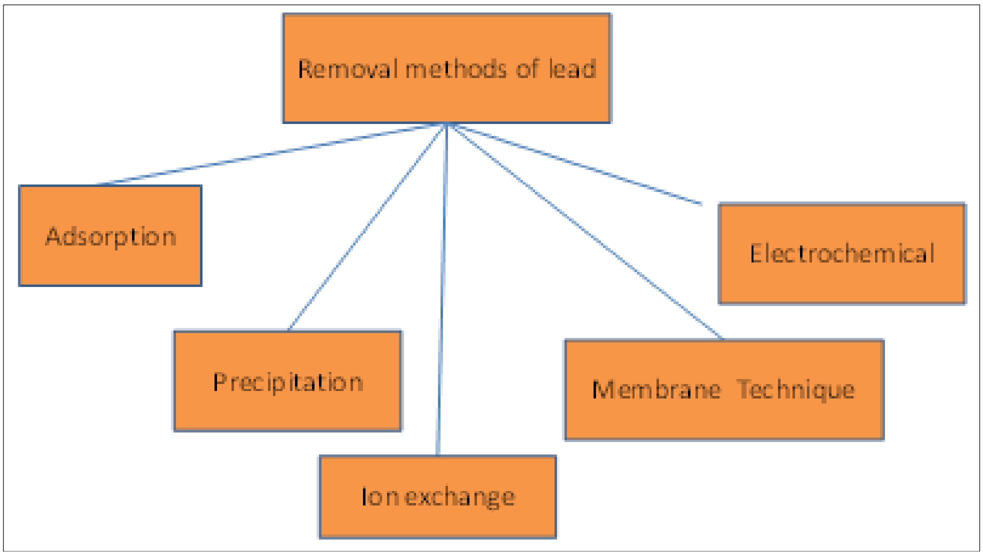
S Sophie Beulah

Abstract
Sustainable development has emerged as the need globally over the past few years. Unsustainable approach due to rapid industrialisation has resulted in water pollution. Pb(II) contaminated wastewater has a significant role in heavy metal ion pollution of water sources. Due to its non-biodegradable nature and continuous use, its concentration accumulates in the environment with increasing hazards. Pb(II) causes pernicious effect on human health. Adsorption has been chosen by many researchers as a suitable removal method for Pb(II). In this review, various adsorbents utilized for the removal of Pb(II) from wastewater has been assessed.

Keywords: Lead (II), adsorbent, pollution, wastewater

1. Introduction

Lead is a heavy, soft, malleable, bluish grey metal [1]. The principal ore of lead is Galena (lead sulfide). The less common ores are anglesite ($PbSO_4$), cerussite ($PbCO_3$) and hydrocerussite [$Pb_3(CO_3)_2(OH)_2$]. Since medieval times lead has been used in piping, building materials, solders, paint, type metal, ammunition and castings. In more recent times, lead is introduced into natural water from a variety of sources such as storage batteries, lead smelting, tetraethyl-lead manufacturing, mining, plating, ammunition, ceramic and glass industries [2, 3]. Inorganic forms of lead typically affect the central nervous system, peripheral nervous system, renal, gastro vascular, gastrointestinal and reproductive system [4]. According to World Health Organization (WHO), the maximum permissible limit of lead in drinking water is 0.05 mg/L. The permissible limit (mg/L) for Pb (II) in wastewater, given by Environmental Protection Agency (EPA), is 0.05 mg/L. [5, 6]. Various removal methods of lead are as given as flowchart. Adsorption is proposed as an economical and effective method for the retention of lead ions from industrial wastes. In this review, the various adsorbents used for the removal of Pb^{2+} ions from wastewater have been presented.



2. Various Experimental findings in literature

2.1 Adsorption by ferric activated sludge-based adsorbent derived from biological sludge

Guoren Zu *et al*. (2019) prepared ferric activated sludge-based adsorbent (SBA) through pyrolysis treatment of biological sludge, and the adsorbent was applied to adsorb Pb^{2+} ions from aqueous solution. The ferric-activated SBA showed a porous structure development and enhanced Pb^{2+} ions removal, with the maximum sorption capacity of 42.96 mg/g. The optimum adsorption was in a wide pH range of 4–6. The adsorption data fitted the Freundlich model indicating heterogeneous lead coverage on the adsorbents. Pseudo-second order model validated the kinetic data, suggesting that the rate-limiting step of the adsorption process was chemical sorption. The mechanism of Pb^{2+} ions removal involved ion exchange, precipitation, and surface complexation. The higher adsorption of ferric-activated SBA was due to the enhancive surface area that provided a larger number of active sites for adsorbate [7].

2.2 Adsorption by Powder activated carbon (PAC) and bentonite (clay)

Naeema (2014) studied the adsorption properties of natural American bentonite and activated carbon, on the removal of Pb^{++} from aqueous solution and showed that the amount of adsorption of Pb^{++} increased with initial metal ion concentration, contact time and solution PH but decreased with amount of adsorbent and temperature. The adsorption process fitted pseudo-second order kinetic model. Langmuir and Freundich adsorption isotherm models were found to be applicable to these adsorption process. Thermodynamic parameters G°, S° and H° of the adsorption process was found to be endothermic. Bentonite was found to be more effective for removal of Pb^{++} than activated carbon [8].

2.3 Adsorption by Arundinaria alpina Stem-Based Activated Carbon

Yosef *et al*. (2021) analysed the activated carbon prepared from locally available bamboo (Arundinaria alpina) in Ethiopia to remove Pb(II) from wastewater. Various effects such as solution pH, initial Pb (II) ion concentration, and adsorbent dose were investigated on a batch adsorption base. Dried Arundinaria alpina stem was activated with potassium hydroxide (KOH) at a ratio of 1:1 (w/v) and carbonized in a furnace at three temperature ranges (500^{o} C, 600 ^{o}C, and 700^{o} C) for 3 h. The physicochemical of Arundinaria alpina stem activated carbon (AASAC) was investigated and the resultant of 500^{o} C treatment setup is found as ideal in terms of yield (40.6 g), ash (3.5%), porosity (0.704%), moisture (7.7%), and iodine number (814.69 mg/g). Further characterization of ideal AASAC was carried out by scanning electron microscopy (SEM), X-ray diffraction (XRD) spectroscopy, and Fourier transform infra-red (FTIR). The optimum Pb (II) removal efficiency of AASAC was 99.8% at pH 5 in a synthetic solution, but the efficiency declined to 60.42% on real industrial wastewater due to the presence of its mixed pollutant nature. Freundlich isotherm model was more favorable than Langmuir with a high correlation coefficient (R^2 - 0.9496) for Pb (II) adsorption [9].

2.4 Adsorption by Activated Carbon Derived from African Arrowroot (Canna indica) Stem

Takele *et al*. (2020) investigated the potential of Canna indica stem-based activated carbon (CISAC) for the removal of Pb (II) ions from synthetic solution and paint industry wastewater. The effects of pH, initial Pb (II) ion concentration, and adsorbent dose were studied using an aqueous solution prepared using pure lead nitrate ($Pb(NO_3)_2$) on a batch mode. Dried Canna indica stem (CIS) was carbonized in a rectangular furnace at 500°C for 2 h and treated with phosphoric acid (H_3PO_4) at a ratio of 1:1 (w/v). Results showed that the CISAC had 5.4% of moisture, 5.0% of ash, 26.7% of volatile matter, 62.9% of fixed carbon, and 797.5 mg/g of iodine number. The Fourier Transform Infrared (FTIR) results showed that the hydroxyl, carboxyl, and phenolic functional groups were dominant in the CISAC surface. Better removal of Pb (II) ion from aqueous solution was achieved at a pH of 5.5, initial Pb (II) concentration of 102.4 mg/L, and an adsorbent dose of 1.4 g using response surface methodology. The highest removal efficiencies of Pb(II) which was achieved from aqueous solution and paint wastewater were 98% and 70%, respectively. The experimental data are fitted with Langmuir and Freundlich isothermic models [10].

2.5 Adsorption by cellulose nanomaterials from the stem of the Erythrina brucei plant

Hizkeal *et al*. (2021) developed both pristine cellulose nanomaterial (CNM) and sodium periodate modified cellulose nanomaterial ($NaIO_4$-CNM) from the stem of the Erythrina brucei plant for the removal of Pb(II) ions from WW. As-prepared CNMs were characterized by X-ray diffraction (XRD), Fourier transform infrared (FT-IR), scanning electron microscope (SEM), and thermogravimetric analysis with differential thermogravimetry (TGA-DTG) analysis. CNMs were tested for the removal of Pb(II) ions from secondary run-off wastewater (SERWW). Langmuir and Freundlich adsorption isotherms were certainly fixed to a maximum Pb(II) ions uptake capability (Qmax) of 91.74 and 384.62 mg g−1 by CNM and $NaIO_4$-CNM adsorbents, respectively. The pseudo-second-order (PSO) kinetics model was well fitted to the uptake process. Results revealed that the percentage removal (%R) of Pb(II) ions was decreased by the presence of nitrogen and organic matter, but not affected by the presence of phosphorous in SERWW. Due to its high efficiency, $NaIO_4$-CNM was selected for the regeneration study. The regeneration study was conducted after desorption of Pb(II) ions from the adsorbent by the addition of HCl, and the regenerated sorbent was reused as an adsorbent for at least 13 successive cycles without significant efficient loss [11].

2.6 Adsorption by ZSM-5/Activated Carbon Composite

Lakshmipathy *et al*. (2021) suggested the implementation of ZSM-5 activated carbon composite as a prolific adsorbent for the continuous elimination of Pb^{2+} ions from water. Continuous adsorption experiments were performed by varying three parameters such as process flow rate (2-6 mL min^{-1}), bed height (2-6 cm), and initial concentration (250–750 mg L^{-1}). The highest loading capacity of the fixed-bed 213.3 mg L^{-1} was achieved with optimal values of 2 mL min^{-1} of flow rate, bed height of 6 cm, and initial concentration of 750 mg L^{-1}, respectively. The breakthrough curves and saturation points were found to appear quickly for increasing flow rates and initial concentration and vice versa for bed depth. The lower flow rates with higher bed depths have exhibited optimal performances of the fixed-bed column. The mechanism of adsorption of Pb^{2+} ions was found to be ion exchange with Na^+ ions from ZMS-5 and pore adsorption onto activated carbon. The breakthrough curves were verified Adams-Bohart, Thomas, and Yoon-Nelson models. The later models showed the best fit to the column data over the Adams-Bohart model that can be utilized to understand the binding of Pb^{2+} ions onto the composite. Regeneration of ZSM-5/activated carbon was achieved with 0.1 M HCl within 60 min of contact time [12].

2.7 Adsorption by edible fungi residue

Jing *et al*. (2021) assessed agricultural waste edible fungi residue (EFR) to adsorb Pb(II) ions in wastewater. The influence of Pb(II) concentration, solution pH, and EFR concentration on the removal efficiency (R) of Pb(II) was investigated with single factor design and response surface analysis. The maximum predicted R for Pb(II) was 76.34% under optimal conditions of Pb(II) concentration of 483.83 mg/L, EFR concentration of 4.99 g/L, and pH of 5.89. The actual experimental value of R reached 76.97% under these conditions. The competition of Pb(II) ions for the available adsorption sites on EFR limited the maximum R. A comparison of Fourier transform infrared spectroscopy before and after the adsorption of Pb(II), indicated that the functional groups of EFR significantly affected the effect of adsorption of heavy metals, and that the adsorption process was primarily affected by functional groups in the range of wavenumbers from 500 to 2,000 cm^{-1} [13].

2.8 Adsorption by Lantana Camara leaves biocarbon

Starlin *et al*. (2018) evaluated the removal of lead from aqueous solution using material prepared from the leaves of Lantana camara plant. It is known as Lantana camara leaves biocarbon (LCLBC) Batch adsorption experiments were conducted to effect of contact time, pH, initial metal ion concentration and adsorbent dosage at room temperature. Maximum adsorption of lead was found at 6. An equilibrium time of 150 required for the adsorption of Pb (II) ions onto the adsorbent. The percentage removal of lead onto the biocarbon was 95.50%. Experimental data were well fitted to the Langmuir equation than to Freundlich equation, indicating monolayer coverage by the Pb (II) ions [14].

2.9 Adsorption using Mucilaginous Leaves of Diceriocaryum eriocarpum Plant

Joshua *et al*. (2015). Prepared an adsorbent using mucilaginous leaves from Diceriocaryum eriocarpum plant (DEP) for the adsorption of lead(II) ion from aqueous solution. Batch experiments were performed on simulated aqueous solutions under optimized conditions of adsorbent dosage, contact time, pH and initial lead(II) ion concentration at 298 K. The Langmuir isotherm model more suitably described the adsorption process than the Freundlich model with linearized coefficients of 0.9661 and 0.9547, respectively. Pseudo-second order kinetic equation best described the kinetics of the reaction. Fourier transform infra-red analysis confirmed the presence of amino (–NH), carbonyl (–C=O) and hydroxyl (–OH) functional groups. Application of the prepared adsorbent to wastewater samples of 10 mg/L and 12 mg/L of lead(II) ion concentration taken from a waste stabilization pond showed removal efficiencies of 95.8% and 96.4%, respectively. Futhermore, 0.1 M HCl was a better desorbing agent than 0.1 M NaOH and de-ionized water [15].

2.10 Adsorption using Moringa oleifera, Prosopis julifora seeds and peanut shell

Gautam *et al*. (2020), dealt with the class of natural adsorbents such as Moringa oleifera, Prosopis julifora seeds and peanut shell for the removal of heavy metal (lead: Pb) from textile wastewater. The above adsorbents were characterized by Fourier transform infrared and scanning electron microscope to predict the functional groups and surface morphology. The efect of adsorbent dose, contact time, metal concentrations and pH on lead removal was studied in batch experiment and found that the maximum removal of lead was found to be 86.0%, 78.0% and 72.0% for M. oleifera, P. julifora seeds and peanut shell, respectively. Langmuir isotherm best correlated to the experimental data for all three cases and 5.6 mg/g, 1.7 mg/g and 1.4 mg/g maximum adsorption capacity of lead was obtained for M. oleifera, peanut shell and P. julifora, respectively. Pseudo-frst-order and pseudo-second-order kinetics study revealed that pseudo-second-order kinetic model followed better correlation coefcient for M. oleifera (R^2=0.998), peanut shell (R^2=0.978) and P. julifora (R^2=0.995) [16].

2.11 Adsorption using Cyperus rotundus (Nut grass) Stalk

Davoud *et al*. (2019) appraised the performance of Cyperus rotundus (Nut grass) Stalk (CRS) in adsorption of lead, heavy metal of aquatic environments. For this purpose, the batch system was used to review the effect pH, mixing time, adsorbent particle size and temperature for Pb(II) removal by the CRS. The highest lead removal efficacy was achieved when pH is 6 The result indicated the maximum Pb(II) adsorption at the contact time of 90 min which implies that increase in contact time leads to a higher lead uptake. The amount of R^2 statistical parameter using the pseudo-second-order is greater as compared with other models. The influence of temperature was determined by using thermodynamic parameters and the results showed removal of lead on the CRS was endothermic, spontaneous and feasible [17].

2.12 Adsorption using Calcium Alginate Beads Doped with Hydrazine Sulphate-Activated Red Mud

Nagababu *et al*. (2017) investigated calcium alginate beads doped with hydrazine sulphate-treated red mud as adsorbent for extracting lead ions from water using batch methods of extraction. Dfferent extraction conditions are optimised for maximum lead extraction. Substantial amount of lead is removed, and the adsorption ability is found to be 138.6 mg/g. Surface characterization using FTIR, EDX, and FESEM confirms that lead is “onto” the surface of the adsorbent. Thermodynamic parameters, adsorption isotherms, and kinetics of adsorption are analysed. Adsorption is “physisorption” in nature and spontaneous. The adsorbent developed can be regenerated using 0.1 M HCl. The regenerated adsorbent can be used as the adsorbent for further removal of lead at least 10 times, and this enables the complete removal of lead from water by repetitive use of the regenerated adsorbent [18].

2.13 Adsorption using cashew nut shells

Kamchai *et al*. (2020) utilised cashew nut shells (CNS), waste from a cashew nut processing factory, as an adsorbent for Pb(II) ions in water. Treatments of CNS with 1M of H_2SO_4, HNO_3, and NaOH solutions were performed to modify their surfaces and improve their adsorption capacities. Characterization of untreated and chemical-treated CNS was carried out using nitrogen adsorption isotherm, elemental (CHN) analysis, Fourier-transform infrared spectroscopy (FTIR), and scanning electron microscopy (SEM) equipped with energy dispersive X-ray analysis (EDX). In the study of Pb(II) removal, various models of adsorption kinetics and isotherms were evaluated against the experimental data. The results showed that H_2SO_4-treated CNS exhibited the highest adsorption capacity. The chemical treatment removes impurities, alters the surface functional groups and improves specifc surface areas and pore volumes of native CNS signifcantly. Surface adsorption and intra-particle difusion steps were found to substantially afect the overall adsorption process of Pb(II) on H_2SO_4-treated CNS [19].

2.14 Adsorption using peas husk waste

Narmeen (2017) researched the possibility of using the peas husk, as biosorbent alternative lowcost to treat lead from wastewater. Peas husk was obtained from waste plant peas on farms or food. Powdered peas husk was used to absorb lead ions from solutions simulation in batch experiments. The effects of contact time, initial metal concentration, dose and pH on the simultaneous adsorption of lead were studied. Experimental results concluded that better absorption efficiency was obtained within 30 minutes of connection time. Maximum removal of lead on the peas husk was achieved when pH is 4 which is about 96.9%. Surface morphology of peas husk was observed before and after application of adsorption process of solutions of lead under Field Emission Scanning Electron Microscopy (FESEM) [20].

2.15 Adsorption using Maize Tassel Based Activated Carbon

Mambo *et al*. (2013) used Maize tassel as the precursor for making activated carbon for the adsorption of Pb(II) ions. The product obtained was characterized and utilized for the removal of Pb(II) from aqueous solutions over a wide range of initial metal ion concentration (10–50 mg/L), contact time (5–300 min), adsorbent dose (0.1–2.5 g), and pH (2–12). The optimum set of conditions for biosorption of Pb(II) ion were found to be initial concentration 10 mg/L, dosage 1.2 g, and pH 5.4.The adsorption data conformed to both the Langmuir and the Freundlich isotherms but fitted best into the Langmuir model. The R^2 for Langmuir equation was 0.9997 and that for Freundlich was 0.9515. The Langmuir monolayer adsorption capacity of the activated carbon was calculated to be 37.31 mg/g. The results indicated that activated carbon might be used to effectively adsorb Pb(II) ions from wastewater treatment [21].

2.16 Adsorption using Kaolinite/Smectite natural composite adsorbent

El Nagger *et al*. (2019) carried out a laboratory batch technique to study the impact of initial concentration, pH, temperature, a dose of adsorbent and contact time on the elimination of lead ions onto oil shell sedimentary rock as natural clay. Two natural inorganic composites Kaolinite/Smectite-A and Kaolinite/ Smectite-B have been used. The lead removal enlarged with rising initial metal solution concentration, contact time and pH. The elimination reaction speed was high at the initial period of contact time and then decreased to attain equilibrium at 45, 30 min for Kaolinite/Smectite-A and Kaolinite/Smectite-B adsorbents, respectively. Mutually, Langmuir and Freundlich's isotherms are applicable to describe the metals adsorption and thermodynamic parameters ΔG; ΔS and ΔH were calculated indicating that the adsorption process is physisorption, spur-of-the-moment and endothermic [22].

2.17 Adsorption using Polyethyleneimine-Functionalized Fe_3O_4 Magnetic Nanoparticles

Yu-tao *et al*. (2020) produced A class of polyethyleneimine (PEI)-functionalized Fe3O4 magnetic nanoparticles (MNPs) through a solvothermal process. The synthetic MNPs have been characterized by multiple technologies and then used for Pb(II) ion sorption from the aqueous media in different conditions. It was found the Pb(II) adsorption behaviors could be well fitted by the pseudo second-order kinetic and Langmuir isotherm models. The maximum Pb(II) adsorption capacity at 25 °C and pH 5.0 was calculated to be 60.98 mg/g. Moreover, effects of temperature, pH, and electrolyte of aqueous phase on the Pb(II) adsorption capacity of MNPs have been carefully examined. The Pb(II) adsorbing capacity was enhanced with temperature or pH rising, but reduced with the addition of various electrolytes. Additionally, the recyclability of synthetic MNPs has been also assessed. The prepared PEI-functionalized MNPs could still maintain good adsorption performance after five cycles of Pb(II) removal. These results indicated that the PEI-functionalized Fe_3O_4 MNPs could be readily synthesized and served as a desirable and economic adsorbent in Pb(II)-contaminated water [23].

Table: Results of Max% of Pb(II) uptake

Name of the adsorbent	Max % of Pb(II) uptake
Ferric activated sludge-based adsorbent	42.96 mg/g
Powder activated carbon (PAC) and bentonite (clay)	-
Arundinaria alpina Stem-Based Activated Carbon	99.8% (Synthetic solution) 60.42% (Industrial wastewater)
Activated Carbon Derived from African Arrowroot (Canna indica) Stem	98%(Aqueous solution) 70%(Industrial wastewater)
cellulose nanomaterials from the stem of the Erythrina brucei plant	91.74%
ZSM-5/Activated Carbon Composite	-
Edible fungi residue	76.97%
Lantana Camara leaves biocarbon	95.5%
Mucilaginous Leaves of Diceriocaryum eriocarpum Plant	95.8%
Moringa oleifera, Prosopis julifora seeds and peanut shell	86%, 78%, 72%
Cyperus rotundus (Nut grass) Stalk	89.9%
Calcium Alginate Beads Doped with Hydrazine Sulphate-Activated Red Mud	91.5%
cashew nut shells	8.73mg/g
peas husk waste	96.9%
Maize Tassel Based Activated Carbon	37.31mg/g
Kaolinite/Smectite natural composite	-
Polyethyleneimine-Functionalized Fe_3O_4 Magnetic Nanoparticles	60.98mg/g

3. Conclusion

Adsorption by various adsorbents has been chosen as effective and cheapest method for Pb(II) removal from aqueous solution by different workers. In this paper, a study between different adsorbents has been made. It could be implied that various bio wastes, composites, nanoparticle absorbents are efficient in removing Pb(II). Large scale application in industries, regeneration and disposal of used adsorbents are the areas needed to be studied extensively

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