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Lead Removal by Waste Organic Plant Source Materials Review

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Abstract: Many works have been made by research scholars to remove lead from wastewaters using different sources of organic materials derived from plant origin. In this paper an attempt has been made to review different sources of waste organic materials and the respective carbon materials which have been used for the removal of lead(II) from water and wastewater based on recent literature review.

1. Introduction

Water pollution has become a serious environmental problem and has attracted global concern throughout the world. Lead occupies an important role in metallurgical electroplating and other chemical industries about 40 % of lead produced is used in battery manufacturing, acid metal plating and finishing, ammunition, tetraethyl lead manufacturing, ceramic and glass industries printing, painting, dying and other industries(1) . The permissible limit of lead in drinking water and surface water intended for drinking, as set by EU, USEPA and WHO are 0.010, 0.015 and 0.010 mg L^{-1} respectively(2). The presence of excess lead in drinking water causes diseases such as anemia, encephalopathy, hepatitis and the nephritic syndrome(3).

2. Lead(II) Removal by Raw Plant Materials

2.1. Lead(II) Removal by Plant Peels

It has been reported that Mexerica mandarin (*Citrus nobilis*) peel was used for the removal of Cu(II), Cd(II) and Pb(II) from ten real wastewater samples from battery industries in Londrina city (Brazil). Based on the experimental data the order of adsorption capacity was found to be Pb(II)>Cd(II)>Cu(II) on the new adsorbent(4). The ability of fruit peel of orange to remove Zn, Ni, Cu, Pb and Cr from aqueous solution by adsorption was studied. The adsorption was in the order of Ni(II)>Cu(II)>Pb(II)>Zn(II)>Cr(II)(5). Studies on orange and lemon peel were used as an adsorbent to investigate to remove copper and lead from industrial waste-water. It was found that the adsorption ability of lemon peels are more efficient than the orange peels(6).

The biomass *Citrus limetta* fruit peel was examined for its potential for Pb^{2+} ions. The Langmuir sorption capacity of 630 mg/g was reported which was found much higher than the capacities of most biosorbents and comparable to those of synthetic ion-exchange resins(7). The uptake of Pb^{2+} by processed citrus peel was also examined by Schiewer and Balaria. The maximum uptake capacity according to the Langmuir model was 658 mg/g, which was reported very high for other biosorbents and similar to some ion exchange resins(8). The adsorption of lead(II) and cadmium(II) on peels of banana has been studied in batch mode. Maximum adsorption capacity of banana peels from Langmuir isotherm indicated that 1 g of banana peels can adsorb 5.71 mg of cadmium and 2.18 mg of lead (9).

The viability of garlic peel (GP) to remove Pb^{2+}, Cu^{2+}, and Ni^{2+} was evaluated. The results showed that the adsorption process could attain equilibrium within 20 min. GP had remarkable higher adsorption affinity for Pb^{2+} than Cu^{2+} and Ni^{2+} with the maximum adsorption capacity of 209 mg/g[(10)]. Native garlic peel and mercerized garlic peel as adsorbents for the removal of Pb^{2+} has been studied. The adsorption capacity of garlic peel after mercerization was increased 2.1 times and up to 109.05 mg/g. FT-IR and scanning electron microscopy (SEM) results indicated that mercerized garlic peel offered more little pores acted as adsorption sites than native garlic peel and had lower polymerization and crystalline and more accessible functional hydroxyl groups, which resulted in higher adsorption capacity than native garlic peels[(11)].

The biosorption ability of potato peels was also investigated for the removal of Pb(II), Cd(II) and Zn(II) from aqueous solutions. The percentage removals were found to be 92, 75 and 42 % for Pb(II), Cd(II) and Zn(II) ions at an initial metal ion concentration of 100 mg/L respectively[(12)]. The ability of ponkan peel to remove Pb(II) ions from aqueous solution by adsorption was studied. The specific surface area and pore volume of ponkan peel waste obtained by BET method were 115.3 m^2/g and 0.30 cm^3/g, respectively. Based on the Langmuir-type isotherms, the maximum uptake capacity of lead ions on ponkan peel was 112.1 mg/g [(13)]. The ability of betel-nut peel (BP), an agricultural waste material, for the removal of Cr^{3+}, Cd^{2+} and Pb^{2+} from aqueous solution has been investigated. The functional groups (C=O, S=O, -OH) present on the carbon surface of BP were responsible for the adsorption of metal ions[(14)].

2.2. Lead(II) Removal by modified Plant Peels

Natural, formaldehyde-treated and copolymer-grafted orange peels (COP) were evaluated as adsorbents to remove lead ions from aqueous solutions. The optimum pH for lead adsorption was found to be 5. The adsorption process was fast, reaching 99 % of sorbent capacity in 10 min for the natural and treated biomasses and 20 min for the grafted material. In the continuous test with the treated biomass, the capacity at complete exhaustion was 46.61 mg/g for an initial concentration of 150 mg/L[(15)]. Orange peel (OP) was modified by KCl to prepare a novel orange peel adsorbent named as KOP. The adsorption behaviours of KOP for five heavy metals (Cu^{2+}, Cd^{2+}, Pb^{2+}, Zn^{2+}, Ni^{2+}) were studied. The maximum adsorption capacities for Cu^{2+}, Cd^{2+}, Pb^{2+}, Zn^{2+} and Ni^{2+} were calculated as 59.77, 125.63, 141.84, 45.29 and 49.14 mg/g, respectively. Recycle and reuse experiments indicated that KOP could be used for more than ten cycles[(16)].

Sulfured orange peel (MOP) was used as adsorbent to investigate its adsorption behaviours of Pb^{2+} and Zn^{2+} from aqueous solutions. The maximum Langmuir adsorption capacities for Pb^{2+} and Zn^{2+} removal by MOP were evaluated as 164 and 80 mg/g, respectively[(17)]. The adsorption of metals (Cu^{2+}, Zn^{2+}, Co^{2+}, Ni^{2+}, Pb^{2+}) from synthetic solutions using the acid-, alkali-, and water-treated orange peels was studied. The adsorption capacity was found to be 7.75 (Pb^{2+}), 6.02 (Ni^{2+}), 5.25 (Zn^{2+}), 3.65 (Cu^{2+}), and 1.82 mg/g (Co^{2+}) using orange peel[(18)]. A comparative study of the adsorption capacity of the chemically modified orange peel was performed against environmentally problematic metal ions, namely, Cd(II), Cu(II) and Pb(II) ions from aqueous solutions. The metals uptake by MOP was rapid and the equilibrium time was 30 min. Chemically modified orange peel (MOP) showed a significantly higher adsorption capacity compared to original orange peel(OP)[(19)].

The adsorption behaviour of chemically modified orange peel was studied for the removal of Cu(II), Pb(II) and Zn(II) ions from aqueous solutions. Equilibrium was well described by Langmuir equation with the maximum adsorption capacities of Cu(II), Pb(II) and Zn(II) ions was found to be 70.73, 209.80 and 56.18 mg/g, respectively[(20)]. Experiments with chemically modified activated carbon prepared by *Citrus limettioides* peel and seed indicated that the adsorption capacity of CLPC and CLSC was found to be 166.67 and 142.86 mg/g[(21)]. Adsorption of Pb^{2+} by alkali-treated *Citrus limetta* peel was studied from aqueous $PbNO_3$ solutions of different concentrations. The equilibrium sorption capacity was observed to be 630 mg/g[(22).] Pomelo peel as biosorbent using the zinc chloride activating method was used in laboratory to test its capability of removing Pb^{2+} from wastewater. The optimal conditions for the adsorption were found to be: 5.3-6.5 initial pH of the wastewater, 1.5 h of exposure duration, 10 g/L adsorbent dosage, 100 mg/L of initial Pb^{2+} concentration of wastewater at 30°C. Under the given experimental parameters, the adsorbent could remove more than 90 % of Pb^{2+} from the wastewater[(23)]. The adsorption effects of $ZnCl_2$-modified pomelo peel powder on wastewater containing Pb(II) ions was also studied[(24)].

The adsorbent was prepared from grapefruit peel by activation (GPA) with $ZnCl_2$ and employed to remove Pb(II) from wastewater. The removal rate of Pb(II) ions was found to be more than 90 % and the sorption capacity was 12.73 mg/g, respectively[25]. Massocatto et al reported the chemically modified banana peels were used as adsorbents for the removal of lead(II) from aqueous solutions[26]. The ability of activated carbon from cassava peels to remove Cu(II) and Pb(II) from hospital wastewater was investigated. The study showed that pH 8 was the best for the sorption of both metal ions onto the biosorbent. The Langmuir model showed that the biomass has a higher sorption capacity for Cu(II) than Pb(II) (5.80 mg/g for Pb(II) and 8.00 mg/g for Cu(II)[27]. Removal of lead(II) and copper(II) from aqueous solutions was studied using pomegranate peel (raw), activated carbon prepared from pomegranate peel (AC1) and activated carbon prepared from chemically treated pomegranate peel (AC2 and AC3). The optimum pH required for maximum adsorption was found to be 5.6 and 5.8, for lead and copper, respectively. Equilibrium was achieved in 2 h[28]. Modified watermelon peel adsorbent was also used for the removal of Pb(II)[29]. A cost-effective biosorbent was prepared by a green chemical modification process from muskmelon peel by saponification with alkaline solution of $Ca(OH)_2$ and tested its adsorption behaviour for lead ions. Results showed that the optimal equilibrium pH range for 100 % adsorption was from pH 4 up to 6.4. Adsorption equilibrium was attained within 10 min. The maximum adsorption capacity for lead ions was found to be 167.80 mg/g[30].

2.3. Lead(II) Removal by Plant Shells, Hulls and Husks

The potential of shells of hazelnut (HNS) and almond (AS) to remove Pb^{2+} from aqueous solutions was investigated in batch experiments. The equilibrium sorption capacities of HNS and AS were 28.18 and 8.08 mg/g, respectively. The binding of metal ions involved three mechanisms: the first is adsorption, the second of these being simple ion exchange and the third one is through the formation of complexes[31]. The role of pH in the removal of Cd(II), Ni(II), Pb(II) and Cr(VI) from aqueous solution by biosorption using African white star apple (Chrysophyllum albidium) shell was examined. The results indicated that the optimum pH for sorption of Cd(II) and Ni(II) was 6.0 while Pb(II) and Cr(VI) was 7.0 and 2.0 respectively[32]. The potential of almond shells was assessed for adsorption of heavy metal ions such as Pb^{2+} and Cd^{2+} from aqueous solution[33]. The removal of Pb^{2+} and Cd^{2+} from aqueous solution using *Annona squamosa* (custard apple) fruit shell (CAS) was investigated by Isaac and Sivakumar. The maximum loading capacity of Pb^{2+} and Cd^{2+} was found to be 90.93 and 71.0 mg/g at pH 5.0[34].

Adsorption of lead from aqueous solutions by using chestnut shell as an adsorbent was applied to investigate the influence of the adsorbent dose, stirring speed and pH[35]. The removal capacity of toxic heavy metals (Cd, Cr and Pb) using waste eggshell was studied by Park et al[36]. The use of peanut hulls, for copper and lead removal was studied by Oliveira et al[37]. Experiments with pigeon peas hulls at pH 4.0 indicated that the thermodynamic properties for the simultaneous removal of Pb(II) and Ni(II) was found to be endothermic over the temperature range 293-313 K[38]. Rice husk has been tested for the removal of lead from aqueous solutions by Khalid et al[39]. Rice husk ash is a solid obtained after burning of rice husk. Naiya et al reported the adsorption of Pb^{2+} from aqueous solution on rice husk ash in batch studies. Optimum conditions for Pb^{2+} removals were found to be pH 5, adsorbent dose 5 g/L and equilibrium time 1 h. The adsorption capacity of rice husk ash for Pb^{2+} ions was 91.74 mg/g[40]. Rice hull ash has also been explored as an adsorbent for the removal of Pb(II) ions from an aqueous solution by Wang and Lin[41]. Meena et al reported the adsorption of Pb^{2+} and Cd^{2+} ions using mustard husk as an adsorbent. Maximum removal of Pb^{2+} and Cd^{2+} ions on mustard husk was at the pH of 6 and 4, respectively. The adsorption capacities of mustard husk for Cd^{2+} and Pb^{2+} ions are 42.85 and 30.48 mg/g, respectively[42]. The adsorption potential of black gram husk was tested for the removal of Pb, Cd, Zn, Cu and Ni ions from water[43].

2.4. Lead(II) Removal by modified waste plant Shells, Hulls and Husks

Kazemipour et al developed the adsorption of Pb^{2+}, Zn^{2+}, Cu^{2+} and Cd^{2+} onto the carbon produced from nutshells of walnut, hazelnut, pistachio, almond and apricot stone. All the agricultural shells or stones used were ground, sieved to a defined size range and carbonized in an oven. Time and temperature of heating were optimized at 15 min and 800°C, respectively, to reach maximum removal efficiency[44]. Issabayeva et al reported the palm shell activated carbon to remove Pb^{2+} ions from aqueous solutions. Palm shell activated carbon showed high adsorption capacity for Pb^{2+} ions at pH of 5 with an ultimate uptake of 95.2 mg/g[45]. Issabayeva et al also reported the continuous adsorption of Pb^{2+} ions from aqueous solution on commercial, granular and unpretreated palm shell activated carbon at the presence of complexing agents (malonic and boric acids). The breakthrough period was longer at pH 5 than at pH 3 indicating higher adsorption capacity of Pb^{2+} ions at higher pH[46]. The adsorption of copper, nickel and lead ions from synthetic semiconductor industrial wastewater using activated carbon prepared from palm shell has been investigated and reported by Onundi et al. Results showed that pH was the most suitable, while the maximum adsorbent capacity was at a dosage of 1 g/L, recording a sorption capacity of 1.337 mg/g for lead, 1.581 mg/g for copper and 0.130 mg/g for nickel(47).

Activated carbon was synthesized from agricultural by-products, such as peanut shells and used for the removal of Cd^{2+}, Cu^{2+}, Pb^{2+}, Ni^{2+} and Zn^{2+} ions from aqueous solutions(48). Chamarthy et al prepared adsorbents from peanut shell by thermal treatment in the presence of phosphoric acid or citric acid and used it for the adsorption of Cd(II), Cu(II), Ni(II), Pb(II) and Zn(II) ions(49). Activated carbon prepared from peanut shell (PAC) was studied for the removal of Pb(II) from aqueous solution. The impacts of the Pb(II) adsorption capacities of the acid-modified carbons oxidized with HNO_3 were also investigated. A comparative study with a commercial granular activated carbon (CAC) showed that PAC was 10.3 times more efficient when compared to GAC. The capacity of Langmuir adsorption was noted as 35.5 mg/g (50).

Acid formaldehyde pre-treated chestnut shell was used as an adsorbent, and the influence of initial cation concentration, temperature and pH was investigated towards the optimization of Pb^{2+}, Cu^{2+} and Zn^{2+} ions removal from aqueous solutions(51). Carbon derived by reacting coconut shell with sulphuric acid after steam activation was studied for the removal of Cd(II) and Pb(II) from wastewaters. The carbon showed more than 99 % removal of Cd(II) and Pb(II) ions respectively(52). Removal of lead from aqueous solutions by adsorption onto coconut shell carbon was investigated. Batch experiments revealed that the highest lead adsorption capacity was observed at pH 4.5. The maximum lead adsorption capacity estimated with Langmuir model was found to be 26.50 mg/g(53). Adsorption behaviour of Pb(II) from aqueous solutions onto coconut shell based granulated activated carbon and alkali sulphide treated activated carbon has been studied by Goel et al(54). Experiments with coconut shells under column studies indicated that the breakthrough curves for multiple elements under a flow rate of 2mL/min and a bed height of 10 cm gave the order of adsorption capacity Cu^{2+} > Pb^{2+}> Cd^{2+} > Zn^{2+} > Ni^{2+} (55).

Coconut shell and seed shell of palm tree were chemically activated by phosphoric acid at 300°C for 16 hours. The carbons activated at 400°C displayed better adsorption capacities. The amount of metal adsorbed on the activated carbons increased in the order Zn, Cu and Pb respectively(56). The adsorption of Pb^{2+}, Cu^{2+}, Cd^{2+} and As^{3+} from aqueous solution onto coconut (cocos nucifera L) shell (CNS) has been studied. The maximum ion adsorption capacities followed the trend $Pb^{2+} > Cu^{2+} > Cd^{2+} > As^{3+}$ and the percentage removal was found to depend on the concentration of the adsorbent present, solution pH and the temperature. The activation energy of CNS was found to be 7.99, 3.79, 10.24 and 53.977 KJ/mol for Pb, Cu, Cd and As, respectively(57). The adsorption of heavy metal ions (Pb^{2+} and Cd^{2+}) from wastewater using activated carbon derived from Borassus aethiopum (seed shells) and cocos nucifera (shells) was studied. The monolayer adsorption capacity, Q_o for Pb(II) was found to be 12.19 mg/g and 24.39 mg/g for activated BASS and CONS, respectively(58).

The removal of Pb(II) from aqueous solution by chemically modified walnuts shells was also studied(59). Wolfova et al reported the walnut shell activated with different chemical reagents as adsorbents were used to remove lead from aqueous solutions(60). The activated carbon synthesized from watermelon shell (GACW) and walnut shell (GACN) and used as an alternative low-cost adsorbent for the removal of lead(II) and zinc(II) ions from aqueous solutions. The GACN has 10 % more surface area (789 m^2/g for GACN and 710 m^2/g for GACW) and 13 % more pore volume than GACW(61). Senthil Kumar et al also reported the adsorption of Pb(II) ions from aqueous solutions using sulphuric acid treated cashew nut shell as an adsorbent. The maximum adsorption capacity of Pb(II) ions were found to be 408.6, 432, 446.3 and 480.5 mg/g respectively, at different temperatures (30, 40, 50 and 60°C)(62).

Activated carbon produced from fluted pumpkin (*Telfairia occidentalis*) seed shell(63), Oil palm and Coconut shells(64) was also utilized for the removal of lead(II), and Ni(II), Pb(II) and Cr(VI) ions from aqueous solutions. Palm kernel shell and Palm kernel husk, two readily available agricultural waste products have been used as low-cost potential adsorbents to remove chromium and lead from drill cuttings. Chromium and lead removal was found to be pH dependent with the optimum pH for chromium removal being 3 while that of lead was 5(65). The ability of low-cost activated carbon prepared from *Ceiba pentandra* hulls, an agricultural waste material, for the removal of lead and zinc from aqueous solutions has also been investigated(66). Removal of lead(II), Zinc(II), copper(II) and cadmium(II) from aqueous solutions using activated carbon prepared from Phaseolus aureus hulls (ACPAH), an agricultural waste was also studied. The maximum adsorption capacity values of ACPAH for metal ions were 21.8 mg/g for Pb(II), 21.2 mg/g for Zn(II), 19.5 mg/g for Cu(II), and 15.7 mg/g for Cd(II) respectively(67).

It was reported that tartaric acid modified rice husk is a potentially useful adsorbent in batch studies for the removal of copper and lead from aqueous solutions, the various affecting parameters such as pH, initial concentration of adsorbate, particle size, temperature, contact time were also studied(68). Sulphuric acid treated rice husk was used to remove inorganic heavy metals such as Cd(II), Hg(II) and Pb(II) from aqueous system(69). The fixed bed column study using phosphate treated rice husk for the removal of lead, copper, zinc and manganese have been conducted with different bed depth by keeping the flow rate at 20 mL min^{-1} and concentration of the metal ion solution at 10 mg/L. The breakthrough time was found to increase with increase in bed height from 10 to 30 cm. Different column design parameters like depth of exchange zone, adsorption rate and adsorption capacity were also calculated(70).

Activated carbon prepared from peanut husks (PHC) has been used for the adsorption of Pb^{2+}, Zn^{2+}, Ni^{2+} and Cd^{2+} from aqueous solution. The results showed that Pb^{2+} has best affinity to PHC than Cd^{2+}, Ni^{2+}, and $Zn2^{+}$ (71). Dwivedi et al have explored a novel application of modified groundnut husk on mitigation of toxic Pb^{2+} and Cd^{2+} ions in an aqueous phase(72). Activated carbon was prepared from hazelnut husks with zinc chloride activation at 973 K in nitrogen atmosphere. BET surface area of the activated carbon was found to be 1092 m^2/g. The maximum adsorption capacity of the adsorbent for Cu(II) and Pb(II) ions was calculated from the Langmuir isotherm and found to be 6.645 and 13.05 mg/g, respectively(73).

2.5. Lead (II) removal by native and modified bran as adsorbents

Bran is the hard outer layer of grain, such as rice, corn (maize), wheat, oats, barley and millet. It is an integral part of whole grains, and is often produced as a by-product of milling in the production of refined grains. The effectiveness of native and chemically modified rice bran to remove Pb(II) ions from aqueous solution was examined by Fatima et al(74). The sorption capacities q (mg/g) increased in the following order: NaOH (147.78), $Ca(OH)_2$ (139.08), $Al(OH)_3$ (127.24), esterification (124.28), $NaHCO_3$ (118.08), methylation (118.88), Na_2CO_3 (117.12) and native (80.24).

The adsorption of Pb^{2+} ions from aqueous solutions on wheat bran was investigated by Bulut and Baysal. The maximum Pb^{2+} ions sorption capacities on wheat bran at 20, 40 and 60°C are 69.0, 80.7, and 87.0 mg/g, respectively(75). Sulphuric acid-treated wheat bran was used as an adsorbent to remove Pb^{2+} ions from aqueous solution. The equilibrium time for the process was determined as 2 h and yielded highest adsorption at pH 6.0. The equilibrium data obtained at different temperatures fitted to the non-linear form of Langmuir, Freundlich and Redlich-Peterson and linear form of Langmuir and Freundlich models. The maximum adsorption capacity which was obtained as linear form of Langmuir model increased from 55.56 to 79.37 mg/g with increasing temperature from 25 to 60°C(76).

Maize bran as a low-cost biosorbent for the removal of Pb^{2+} ions from an aqueous solution was reported by Singh et al. Optimum removal at 20°C was found to be 98.4 % at pH 6.5, with an initial Pb^{2+} ion concentration of 100 mg/L. The adsorption data fitted the Langmuir isotherm. In addition, authors showed that the adsorption in the initial stages was due to the boundary layer diffusion, whereas in the later stages adsorption was due to intraparticle diffusion(77).

2.6. Lead(II) removal from Seeds and Stones of Different agricultural Products

Biosorption potential of *Prosopis juliflora* seed powder for Pb^{2+} ions from aqueous solution was investigated by Jayaram and Prasad in batch experiments. The maximum uptake of metal ions was obtained at the pH 6.0. Adsorption equilibrium was established at 360 min(78). An adsorption method using *Capsicum annuum* seeds as adsorbent for the removal of Pb^{2+} ions from aqueous solution in a batch system was developed by Ozcan et al. The authors showed that mechanism involved in adsorption of Pb^{2+} ions by seeds of *Capsicum annuum* was mainly attributed to Pb^{2+} binding of amino and hydroxyl groups. The maximum adsorption capacity was 1.87x 10^{-4} mol/g with adsorption equilibrium of 40 min(79). The use of peach and apricot stones as adsorbents for the removal of Pb^{2+} ions from aqueous solution was presented by Rashed. The maximum uptakes of Pb^{2+} on apricot and peach stones were about 1.31 and 2.33 mg/kg, respectively(80). The adsorption potential of plum stones was studied for the removal of Pb^{2+} from aqueous solutions by Gala and Sanak-Rydlewska. The maximum sorption capacity of plum stones was found for 21.2 mg/g(81).

2.7. Lead(II) removal from modified Seeds and Stones

Palmyra palm fruit seed carbon was prepared by mixing the seed with concentrated sulphuric acid in 2:1 ratio and kept at 200°C for 10 hours. Results showed that a quantitative removal of 20 mg/L of Pb(II) solutions, a minimum carbon dose of 200 mg was required at pH 4.0-6.0 respectively[82]. Low-cost activated carbon was prepared from apricot stone by chemical activation with sulphuric acid for the adsorption of Pb(II) from aqueous solution. The estimated maximum adsorption capacity of lead ions was found to be 21.38 mg/g[83]. Apricot stones were carbonized and activated with sulphuric acid and used to remove Ni(II), Co(II), Cd(II), Cu(II), Pb(II), Cr(III) and Cr(VI) ions from aqueous solutions. Adsorption capacities for the metal ions were obtained in the descending order of Cr(VI) > Cd(II) > Co(II) > Cr (III) > Ni(II) > Cu(II) > Pb(II) for the activated carbon prepared from apricot stone[84].

A low-cost activated carbon from Date stone, an agricultural solid waste by-product, was prepared by chemical activation with sulphuric acid for the removal of lead and zinc from aqueous solutions. The maximum removal of Pb(II) and Zn(II) was observed at pH 6.0 (94.4 %) and pH 7.0 (93.2 %) respectively at an initial concentration of 20 mg/L. The adsorption capacities of Pb(II) and Zn(II) were 19.64 and 10.41 mg/g[85]. The removal efficiencies of Cu^{2+}, Cd^{2+}, Ni^{2+}, Pb^{2+}, Fe^{2+} and Zn^{2+} from aqueous solution with olive stone activated carbon(OSAC) were investigated by Alslaibi et al[86]. Phosphorylated tamarind nut carbon was applied for the removal of nickel and lead ions from aqueous solutions[87].

2.8. Lead(II) removal using Miscellaneous Agricultural Waste

Nadeem et al reported the steam activated and chemically modified carbons from husk and pods of Moringa oleifera, an agricultural waste were used for the removal of lead(II) from aqueous solutions[88] . The chemically modified activated carbon prepared from the various agricultural wastes such as corncob[89], Tamarind wood[90,91], *Pongamia pinnata* pods[92], cotton stalk[2], lotus stalk[93], cow bone[94], *Enteromorpha prolifera*[95], *Spartina alterniflora*[96], *Polygonum orientale* Linn[3], coffee residue[97], *Eucalyptus camaldulensis* Dehn. Bark[98], Rose (*Rosa centifolia*) petals[99], Maize leaf[100], Acacia tortilis leaves[101], *Portulaca oleracea* leaves[102], Date tree leaves[103], Bael tree leaf power[104], bael leaves[105], Palm kernel fibre[106], grape stalk waste[107], peach palm waste[108], okra wastes[109], pomegranate waste[110], etc were also employed for the removal of toxic inorganic and organics from water and wastewater.

Conclusion

Little efforts seem to have been made to carry out a cost comparison between activated carbon and various nonconventional adsorbents. This aspect needs to be investigated further in order to promote large-scale use of non-conventional adsorbents. In spite of the scarcity of consistent cost information, the widespread uses of low coat adsorbents in industries for wastewater treatment applications today are strongly recommended due to their local availability, technical feasibility, engineering applicability, and cost effectiveness. If low-cost adsorbents perform well in removing heavy metals at low cost, they can be adopted and widely used in industries not only to minimize cost inefficiency, but also improve profitability.

In addition, if the alternative adsorbents mentioned previously are found highly efficient for heavy metal removal, not only the industries, but the living organisms and the surrounding environment will be also benefited from the decrease or elimination of potential toxicity due to the heavy metal. Thus, the use of low-cost adsorbents may contribute to the sustainability of the surrounding environment.

Undoubtedly low cost adsorbents offer a lot of promising benefits for commercial purpose in the future.

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