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Mini Review

Lead Removal from Water by Low Cost Adsorbents: A Review

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Abstract

Lead is known to be toxic for human's body systems i.e. nervous, digestive and skeleton system even if it is present in low levels. The rapidly increasing population is appending many problems concerning water pollution. The presence of lead metal in drinking water is of special concern because of its persistence and toxicity. In this review paper lead toxicity, its contamination in water and the effects of various factors on adsorption of lead, reaction kinetics, nature of link between lead and surface of media are described. The general prominence has been given on the utilization of different agricultural, industrial wastes and low cost synthetic oxides as adsorbents for the removal of poisonous lead from water.

Keywords: Adsorption; Adsorbents; Lead; Water; Toxic.

Introduction

Lead and its toxicity

Lead has environmental importance due to its well known toxicity [1] and intensive use in industries such as storage-battery manufacture, printing, pigment manufacturing, petrochemicals, fuel combustion and photographic materials [2]. Assimilation in the human body of relatively small amounts of Pb(II) over a long period of time can Lead to malfunctioning of certain organs and chronic toxicity [3]. Pb(II) is one of these heavy metals, and can be introduced into liquid wastes from different industries. In water, Pb(II) tends to accumulate in aquatic organisms through the food chain and by direct uptake [4]. It can damage practically all tissues, particularly the kidneys and the immune system. Intense exposure to high Pb(II) levels (from 100 to 200 gram/day) causes encephalopathy with the following symptoms: vertigo, insomnia, migraine, irritability, and even convulsions, seizures, and coma [5, 6]. The current annual worldwide production of Pb(II) is approximately 5.4 million tons and continues to rise. Sixty percent of Pb(II) is used for the manufacturing of batteries (automobile batteries, in particular), while the remainder is used in the production of pigments, glazes, solder, plastics, cable sheathing, ammunition, weights, gasoline additive, and a variety of other products. Such industries continue to pose a significant risk to workers, as well as surrounding communities. There is a need to treat the waste water to bring the concentration of toxic elements below the recommended release limit [7]. Adsorption is one of the methods commonly used to remove heavy metal ions from various aqueous solutions with relatively low metal ion concentrations. The efficiency of adsorption relies on the capability of the adsorbent to adsorb metal ions from the solutions onto its surfaces.

Level of Lead Contamination in Drinking Water

The current EPA Pakistan and WHO drinking water standard for Pb(II) is 0.05 mg/L and 10 μg L^{-1}, respectively. Pb(II) accumulates mainly

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in bones, brain, kidney and muscles and may cause many serious disorders like anemia, kidney diseases, nervous disorders and sickness even death [8]. Considering drastic effects of Pb(II), for Pakistan the value has been set at less than or equal to 0.05 mg/L. It is therefore, essential to remove Pb(II) from wastewater before disposal. Most of the Pb(II) in drinking water arises from the plumbing systems in the buildings. Different measures should be taken to reduce the amount of Pb(II) in drinking water [9, 10].

Lead Contamination in Drinking Water in Pakistan and Worldwide

Surface and ground water contamination with respect to trace elements by industrial and domestic effluents has increased in recent years [11, 12, 13, 14, and 15]. All the water bodies including rivers, canals and the drainage canals are being used by industries, industrial estates and municipalities of towns and cities for the discharge of effluents from industrial, construction, transportation and other activities. The untreated effluents and solid wastes are dumped into rivers and canals [16]. About 9000 million gallons of wastewater is being discharged daily into the water bodies from industrial sector of Pakistan [17]. Therefore, it is expected that surface and ground water may get contaminated widely. Generally, all heavy metals that exist in underground and surface waters are in low concentration and in colloidal, particulate, and dissolved phases [18]. The elevated concentrations of trace elements (zinc, copper, iron, manganese, cadmium, nickel and lead) in Kabul River and its tributaries in NWFP [19] were reported. The increased levels were mostly linked to industrial and domestic wastewater flow into this river. Discharging untreated industrial effluents in the surface drains contaminate the surface waters and hence could affect agricultural production. The reported concentration of Pb(II) in surface water samples collected from various sites of NWFP ranged from 0.02-0.38 mg/L with an average value of 0.16 mg/L. Similarly, the values observed for Pb(II) in surface water samples collected from Malir River, Karachi (Sindh) ranged from 0.09 to 0.32 mg/L with an average value of 0.19 mg/L. The concentration of Pb(II) in ground water samples collected from various sites of NWFP varied between 0.02- 0.73 mg/ L with an average value of 0.33 mg/L. While, the concentration of Pb(II) varied between 0.1-0.24 mg/L with an average value of 0.15 mg/L in ground water samples collected from Korangi Industrial Area, Karachi, Sindh. The results obtained in this study could be compared with those reported by other investigators. Khattak and Rehman [19] reported the maximum concentration of 0.14 mg/L for Pb(II) in the Kabul River at Pirsabak NWFP-Pakistan. Now it is understood that variations from river to river and other surface water are mainly because of diverse anthrapogenic activities (industrial, agricultural and domestic) and different ecological conditions. But the general comparison indicates that the concentration of selected trace elements in this study is quite high and could be considered as contaminated by industrial effluents. A total of 16 surfaces and 8 ground water samples were collected from NWFP while 8 surface and 4 ground water samples from Karachi (Sindh) analyzed [20] for trace elements concentration with the help of atomic absorption spectrophotometer. The observed values were also compared with USEPA (United State Environmental Protection Agency) [21] and WHO (World Health Organization) [22] recommended levels as well as with the concentrations reported by other investigators. The comparison showed that the level of Pb(II) was quite high. The Pb(II) content in gasoline sold in India, Pakistan and Nepal ranges from 0.42 - 0.82 g/L, which is among the highest in the world [23].

The Centers for Disease Control (CDC) currently considers Pb(II) poisoning the foremost environmental health threat to children in the United States. The diagnosis of Pb(II) toxicity has traditionally been based on significantly elevated blood Pb(II) levels. However, data now indicates that low-level exposures resulting in blood Pb(II) levels below 10 μg/dL result in cognitive dysfunction, neurobehavioral disorders, neurological damage, hypertension, and renal impairment [24].

Conventional Methods for Lead Removal

Several conventional methods exist for the removal of heavy metal pollutants from wastewater. These methods include precipitation, electroplating, chemical coagulation, ion-exchange, membrane separation, and electrokinetics. However, these methods often acquire high operational costs [25-27].

A Best Contrivance for lead removal

The greater environmental awareness in both the public and regulatory sphere in recent years has necessitated the treatment of industrial effluent. As such there has been a great deal of research into finding cost-effective methods for the removal of contaminants from wastewater. In recent years considerable attention has been devoted to the study of removal of heavy metal ions from solution by adsorption. Natural materials that are available in large quantities or certain waste from agricultural operations may have potential to be used as low cost adsorbents, as they represent unused resources, widely available and are environmentally friendly [28]. Some investigations on the removal of heavy metal ions with many agricultural by products have been reported [29- 31]. Adsorption methods were found to be more effective and attractive due to its lower costs and the higher efficiency of heavy metal ions removal from wastewater. Activated carbon is a potential adsorbent for the removal of several organic and inorganic pollutants [32]. Many physico-chemical methods have been proposed for their removal from industrial effluents [33]. Adsorption is an effective purification and separation technique used in industry especially in water and wastewater treatments [34]. Cost is an important parameter for comparing the sorbent materials [35].

Different adsorbents used for lead removal

Today, with the rapidly increasing urban population, water resources becoming scant, there is a strong need to reconsider our consumption patterns and the way we use our water resources. Developing countries suffer from water pollution; the high costs of contents and treatments make the major problems in these countries. Search for a cheaper alternative reveals that utilizing natural processes and materials significantly reduce high cost. Natural adsorbents such as ores, rocks, plant straw and the dried aquatic plants are one of the effective and environmentally sound low cost materials for treatment of polluted water from heavy metals. Alum was used with ferric chloride as coagulators for the wastewater treatment [36, 37]. Many alkalis were currently being used for environmental control purposes particularly in wastewater treatments [38]; the most commonly used were lime and sodium carbonate. Adsorption of the heavy metals ions from solution has been studied by others using naturally occurring minerals. Pyrolusite has been used for adsorption of Pb, Zn and Mg ions from their aqueous solution [39]. Zeolites have been used for the removal of heavy metals from wastewater [40]. The adsorption techniques have been used for the removal of heavy metals from polluted water [41, 42]. The adsorbents that have been used for the removal of heavy metals [43] solution include soils and carbonaceous material developed from fertilizer waste slurry [44]. Adsorption of heavy metals ion from polluted water by activated carbons from date pits [45] and by ferrite and chelating resin method [46] has also been studied. Detailed investigations on the adsorption of metal ions on commercial activated carbons were studies [47, 48]. Adsorption of Pb(II) at clay_surface was studied [49]. Mineral ores was used as adsorbents for the adsorption of ions from liquid phase [50]. Kaolinite and alumina were used for the removal of Pb(II) from incinerated lubricating oil [51]. Manganese, Cobalt, Nickel, Zinc and Lead were strongly adsorbed by the calcite surface [52]. Coffee has been used for the removal of Pb, Cu, Hg, Cd and Zn from drinking water at a rate of 78-90 percent of the dissolved heavy metals [53]. Different naturally occurring adsorbents like activated carbon [54-57], tea waste [58], egg shells [59], mineral mixtures [60], and rice husks [61] were used as adsorbents for industrial waste management. By products of soybean and cottonseed hulls, rice straw and sugarcane bagasse were evaluated as metal ion adsorbents in aqueous solutions [62, 63]. Zeolites were used for the purification of wastewater from heavy metals [64]. Removal of Pb(II) from water by adsorption on a Koalinitic clay was investigated [6disord5]. Removal of Pb(II) from water was investigated using alumina (Al_2O_3) as adsorbent. Batch adsorption technique was used to study the effects of pH, temperature, contact time and adsorbate dose. The known quantities of Pb(II) in solutions have been adsorbed on alumina and the concentration of Pb(II) in the solution after adsorption was determined by atomic absorption spectrophotometer [66]. The other objective of adsorbents is also to remove higher amount of toxic metal ions in shorter time. Some of the natural adsorbents being used for the removal of heavy metal ions from aqueous systems are commercial grade natural bentonite, clay aggregate, bamboo dusts, fly ash, zeolite, activated tea waste, modified hollow fiber etc. [67-74].

Agricultural by-products could be heavy metal adsorbents which could be selective for some metal ions [75]. Agricultural material such as banana and orange peels [76] bagasse pith, sawdust wastes [77, 78], maize cob, coconut husk fibres [79, 80], nut shells [81], soybeans and cotton seed hulls have been evaluated for their adsorptive properties. These materials have been reported to adsorb different pollutants such as heavy metal ions, dyestuff and other toxic pollutants [82].

Effects of various factors on adsorption of lead, reaction kinetics nature of link between lead and surface of media

Maximum adsorption capacity of Pb(II) was affected by its initial concentration. Adsorption capacity of Pb(II) increased with the pH and temperature of Pb(II) solution. Langmuir isothermic model fitted the equilibrium data better than the Freundlich isothermic model. The adsorption kinetics followed the pseudo-second-order kinetic model [83]. The adsorption efficiencies were found to be pH dependent, increased by increasing the solution pH in the range from 2.5 to 6.5. The equilibrium time was attained after 120 min and the maximum removal percentage was achieved at an adsorbent loading weight of 1.5 gram. The equilibrium adsorption capacity of adsorbents used for Pb(II) were measured and extrapolated using linear Freundlich, Langmuir and Temkin isotherms and the experimental data were found to fit the Temkin isotherm model [84]. Pb(II) removal recorded its minimum values at pH 2.5. This can be justified on the bases that at lower pH values, the H^+ ions compete with the metal cation for the adsorption sites in the system, which in turn Pb(II)s to partial releasing the later. The heavy metal cations are completely released under extreme acidic conditions [85]. The adsorption percent increases in the pH range of 4.5-6.5 showing the maximum adsorption at pH 6.5. The greatest increase in the rate of adsorption of Pb(II) ions on rice husk, maize cobs and sawdust was observed in the pH range from 2.5 to 4.5. Optimum conditions for Pb(II) removal by rice husk as adsorbent were found to be pH 5, adsorbent dosage 5g/L of solution and equilibrium time 1h. Adsorption of Pb(II) followed pseudo-second-order kinetics. The equilibrium adsorption isotherm was better described by Freundlich adsorption isotherm model. The adsorption capacity (q (max)) of rice husk ash for Pb(II) ions in terms of monolayer adsorption was 91.74 mg/g. The change of entropy ΔS^0 and enthalpy ΔH^0 were estimated at 0.132kJ/(mol K) and 28.923 kJ/mol respectively. The negative value of Gibbs free energy ΔG^0 indicates feasible and spontaneous adsorption of Pb(II) on rice husk ash. The value of the adsorption energy (E), calculated using Dubinin-Radushkevich isotherm, was 9.901kJ/mol and it indicated that the adsorption process was chemical in nature [86].

The uptake of Pb(II) ion increased with an increase in temperature, indicating better adsorption at higher temperatures. The increase in the amount of Pb(II) adsorbed at equilibrium with increases in temperature may be due to the acceleration of some originally slow adsorption steps or to the creation of some active sites on the adsorbent surface [87]. The enhanced mobility of Pb(II) ions from the bulk solution towards the adsorbent surface should also be taken into account [88]. Similar results have been obtained in studies of the adsorption of Pb(II) on rice husk [89]. The adsorption of Pb(II) ions may involves chemical bond formation and ion exchange since the temperature is the main parameter affecting the above two processes [88]. The biosorption of Pb(II) ions from aqueous solution by *Syzygium cumini* L. (Jamun) was studied in a batch adsorption system as a function of pH, contact time, Pb(II) ion concentration, adsorbent concentration and adsorbent size. The biosorption capacities and rates of Pb(II) ions onto *Syzygium cumini* L. (Jamun) were evaluated. The Langmuir, Freundlich, Redlich–Peterson and Temkin adsorption models were applied to describe the isotherms and isotherm constants. Biosorption isothermal data could be well interpreted by the

Langmuir model followed by Temkin model with maximum adsorption capacity of 32.47 mg/g of Pb(II) ion on *Syzygium cumini* L. (Jamun) leaves biomass. The kinetic experimental data were properly correlated with the second-order kinetic model [90]. Removal of Pb(II) from aqueous solutions was studied using Tridax procumbens (Asteraceae). Batch adsorption experiments were performed as a function of pH, contact time, solute concentration and adsorbent dose. The optimum pH required for maximum adsorption was found to be 4.5 for Pb(II). The maximum efficiency of Pb(II) removal by biocarbon was 95%. The results were well fitted by both Langmuir and Freundlich isotherm models [91]. Adsorption behaviour of Pb(II) from aqueous solutions onto nano akaganite powder was studied. Various experimental parameters taken up to generate data included solution pH, contact time, temperature, concentrations of adsorbate and adsorbent. With the increase in pH from 2 to 5, uptake of metal ions increased [92]. The adsorption kinetics followed pseudo-second order model. Both Langmuir and Freundlich models fitted well to the isothermic data.

Advantages of Adsorption process and adsorbents

Adsorption is an effective purification and separation technique used in industry especially in water and wastewater treatments [93]. A number of methods for toxic metal removal from waste water have been used, but most have several disadvantages [94], such as continuous input of chemicals, high cost, toxic sludge generation or incomplete metal removal but the adsorption process has been found advantageous [95] such as: low cost of adsorbent, easy availability, utilization of industrial, biological and domestic waste as adsorbents, low operational cost, ease of operation compared to other processes, reuse of adsorbent after regeneration, capacity of removing heavy metal ions over wide range of pH and to a much lower level, ability to remove complex form of metals that is generally not possible by other methods, environmentally friendly, cost effective and technically feasible. Adsorption process is the best process for removal of metals from wastewater because it is simple, time saving and inexpensive involving no sophisticated apparatus [96-100]. A definite need exists for low cost adsorbents which exhibit superior adsorption capacities and local availability [101].

Conclusion

It is desirable to detect the lead concentration in drinking water and also to provide a suitable, environment friendly and cost effective lead removal process to save millions of people in Pakistan and all over the world from lead poisoning. It is concluded from the above study that the adsorption is a valuable tool for controlling the level of aqueous lead pollution. The utilization of low cost adsorbents for the treatment of wastewater containing heavy metals is helpful as a simple, effective and economical means of wastewater treatment.

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