International Journal of Chemical Studies

P-ISSN 2349–8528
E-ISSN 2321–4902
IJCS 2015; 3(1): 09-14

Received: 16-04-2015
Accepted: 19-05-2015

Manish Singh Rajput
M. Tech.
Department of Chemical Engg.,
Ujjain Engg. College,
Ujjain (M.P.) - 456010, India.

Ashok K Sharma
Associate Professor,
Department of Chemical Engg.,
Ujjain Engg. College,
Ujjain (M.P.) - 456010, India.

Sarita Sharma
Associate Professor,
Department of Chemical Engg.,
Ujjain Engg. College,
Ujjain (M.P.) - 456010, India.

Sanjay Verma
Associate Professor,
Department of Chemical Engg.,
Ujjain Engg. College,
Ujjain (M.P.) - 456010, India.

Correspondence:
Manish Singh Rajput
M.Tech
Department of of Chemical
Engg.Ujjain Engg. College,
Ujjain (M.P.) - 456010, India.

Removal of lead (II) from aqueous solution using low cost abundantly available adsorbents: A review

Manish Singh Rajput, Ashok K Sharma, Sarita Sharma, Sanjay Verma

Abstract
Lead is known to be venomous for human body systems i.e. nervous, digestive and skeleton system even if it is present in low levels. Today's demand for safe, eco-friendly, easily available and low cost adsorbents for the removal of Lead from contaminated waters has necessitated research interest towards the production of low cost alternatives that is why it is an urgent that all possible sources. This review gives some outlines of basic principles of adsorption and adsorption process.

Keywords: Lead; Aqueous solution; Low cost adsorbents; Adsorption.

1. Introduction

Lead is one of the heavy metals that are often found in industrial wastewater and its discharge into the environment poses a serious threat due to its toxicity to aquatic and terrestrial lives [1] [2]. It is a group IV element on the periodic table which is remarkably highly resistant to corrosion in most acid and naturally occur as element buried in the earth crust in insoluble and biologically inoffensive forms [3]. Enhanced industrialization such as manufacturing of storage batteries, television tube, printing, paints, pigments, photographic materials, gasoline additives, matches and explosives brought about lead bearing wastewater [4]. Exposure to Lead is widely recognized as a major risk factor for several human diseases once it goes beyond the World Health Organisation (WHO) maximum permissible limit (3-10μg·L^{-1}) in drinking water [5]. It forms complexes with Oxo-groups in enzymes to affect virtually all steps in the process of haemoglobin synthesis and porphyrin metabolism [6]. Other problems associated with toxic levels of lead exposure are encephalopathy, seizures and mental retardation, anemia and nephropathy [7, 8]. Hence, lead must be removed as much as possible from industrial effluents to prevent environmental hazard from its discharge. Adsorption technology has been widely preferred to other traditional methods such as coagulation, flocculation, filtration, ozonation or sedimentation in the removal of pollutants from wastewater [9]. In this technology, activated carbons are commonly used adsorbent due to their high adsorption capacity, a result of their high surface area and surface reactivity but their regeneration is, however, difficult and expensive [11]. Quest for effective and economical technologies have brought about biosorption. It is based on metal binding capacities of various biological materials, mainly composed of cellulose, hemicelluloses and lignin that make them effective adsorbents for a wide range of pollutants due to the presence of functional groups such as hydroxyl, carboxyl, methoxyl and phenols [12]. Recent studies have shown that heavy metals can be removed using plant materials such as empty palm oil fruit bunch [13], sour soup seeds [14], modified cassava fibre [15], coconut shell [16], duck weed [17], sago waste [18], African spinach stalk [19], palm fruit fibre [20], hop [21], orange peels [22] and spent tea leaves [10, 23]. Banana Stalks (BS) are generated in large amount as waste product after the consumption of banana and these constitute an environmental menace due to the fact that they are left to decompose being of non-economic importance [24]. However, BS is a rich lignocellulosic agricultural waste, whose previous application has been limited to the production of activated carbon for malachite green dye removal [25] and not yet applied to Pb(II) removal [26]. The present study investigated the adsorptive capacity of BS as a low-cost adsorbent for the biosorption of Lead(II) from aqueous solution. The effects of physical parameters such as initial concentration, pH, and temperature and biosorbent dosage on the biosorption process have been investigated. In addition, the biosorption equilibrium isotherms, kinetics and thermodynamic parameters have been determined.

Conventional Methods for Lead Removal

The commonly used procedures for removing metal ions from aqueous streams include chemical precipitation, lime coagulation, ion exchange, reverse osmosis and solvent extraction [27]. The process description of each method is presented below.

Reverse Osmosis: It is a process in which heavy metals are separated by a semi-permeable membrane at a pressure greater than the osmotic pressure caused by the dissolved solids in wastewater. The disadvantage of this method is that it is expensive [27].

Electrodialysis: In this process, the ionic components (heavy metals) are separated through the use of semi-permeable ion selective membranes. Application of an electrical potential between the two electrodes causes a migration of cations and anions towards respective electrodes. Because of the alternate spacing of cation and anion permeable membranes, cells of concentrated and dilute salts are formed. The disadvantage is the formation of metal hydroxides, which clog the membrane [27].

Ultrafiltration: They are pressure driven membrane operations that use porous membranes for the removal of heavy metals. The main disadvantage of this process is the generation of sludge [27].

Ion-exchange: In this process, metal ions from dilute solutions are exchanged with ions held by electrostatic forces on the exchange resin. The disadvantages include: high cost and partial removal of certain ions [27].

Chemical Precipitation: Precipitation of metals is achieved by the addition of coagulants such as alum, lime, iron salts and other organic polymers. The large amount of sludge containing toxic compounds produced during the process is the main disadvantage [27].

Phytoremediation: Phytoremediation is the use of certain plants to clean up soil, sediment, and water contaminated with metals. The disadvantages include that it takes a long time for removal of metals and the regeneration of the plant for further biosorption is difficult. Hence the disadvantages like incomplete metal removal, high reagent and energy requirements, generation of toxic sludge or other waste products that require careful disposal has made it imperative for a cost-effective treatment method that is capable of removing heavy metals from aqueous effluents. The search for new technologies involving the removal of toxic metals from wastewaters has directed attention to biosorption, based on metal binding capacities of various biological materials. Biosorption can be defined as the ability of biological materials to accumulate heavy metals from wastewater through metabolically mediated or physico-chemical pathways of uptake. Algae, bacteria and fungi and yeasts have proved to be potential metal biosorbents. The major advantages of biosorption over conventional treatment methods include [27]:

- Low cost;
- High efficiency;
- Minimisation of chemical and *lor* biological sludge;
- No additional nutrient requirement;
- Regeneration of biosorbent; and
- Possibility of metal recovery.

Relevant Literature

Let us review some agricultural waste by-products used as economic adsorbents for the elimination of heavy metal ions from wastewater in literature.

Jeya kumar R. P. S. and Chandrasekaran V., 2014 studied that adsorption of lead (II) ions onto activated carbons prepared from the marine green Ulva fasciata sp. (CCUC, SSUC and SCUC)and commercially activated carbon (CAC) was investigated with the variation in the parameters of pH, contact time, lead (II) ions concentration and the adsorbent dose. It was reported that adsorption capacities (Q0) were 22.93mg/g for CCUC, 24.15mg/g for SSUC, 23.47 mg/g for SSUC and15.62 mg/g for CAC. It was found that the kinetics data fitted well into the pseudo second-order kinetics and SSUC is a superior adsorbent for the removal of Pb(II) ions from aqueous solution [28].

Abou El-Maaty W.M. *et al.*, 2014, In this work, the potential of activated carbon stems and leaves (ACS, ACL) prepared from dried water hyacinth stems and leaves (DS, DL) by chemical activation with phosphoric acid (1:3) and modified activated carbon stems and leaves (MACS, MACL) with nitric acid (1:1) for the removal of lead from aqueous solution was investigated. It was found in desorption of about 90% of the sorbed lead from carbon was achieved using about 0.6 M HCl [29].

Ghorbani1 A. *et al.*, 2014, studied that use of red mud (bauxite ore processing waste) in removal of lead ions in water samples. The effect of some parameter which is important in adsorption of lead on red mud such as suitable adsorbent dosage, pH and contact time of solution and adsorbent was investigated. The result was found that red mud as solid waste and lowcost adsorbent can be successfully used for the removal of lead ion from aqueous solution [30].

Murthy R. C. *et al.*, 2014, *Cucumissativus* peel (CSP), was investigated as a new adsorbent for Pb(II) removal from aqueous solution under several varying conditions such as pH, adsorbent dosage, and contact time. Maximum metal sorption was found to occur at initial pH 5.0. The adsorption capacity of CSP was found to be 28.25mg/g for initial Pb(II) concentration of 25 mg/l at 25°C [31].

Seniunait J. *et al.*, 2014, studied that water contamination is an actual problem around the world. The main source of contaminated water is the industry. It was also found that coffee grounds are great adsorbent for heavy metal removal from aqueous solutions. Using the >200 >m fraction of coffee grounds for copper removal the treatment efficiency is 85.9% when the metal concentration is 0.5 mg/L, while the lead is 87.2% [32].

Sujata K. *et al.*, 2014, Investigated batch experiments under different experimental conditions have been performed to evaluate the adsorption characteristics of red mud [33].

Singh D. K. *et al.*, 2013, Investigated carbonization of raw biomass directs an attractive approach for improvement of lead(II) uptake from aqueous solutions. The maximum adsorption capacity was found of PSC for Pb(II) was 68.4 mg/g which is relatively large compared to most of the biomass adsorbents as reported. Desorption experiments were carried out using HCl solution and the recovery of Pb(II) from PSC was found 98.5% using 0.2 M HCl [34].

Tahir Uddin N. S. M. and Rahman S. Z. A., 2013, The studied of heavy metals in waste water is known to cause severe damage to aquatic life in which these heavy metals kill microorganism during biological treatment of waste water with a consequent time delay of the treatment process. The effect of contact time, initial metal concentration, dose and pH on the simultaneous adsorption of lead were studied. It was found that maximum removal of lead on the charcoal and peanut shell was achieved when pH is 4 which is about 98.57 % [35].

Pandhare G. G. *et al.*, 2013, the studied on performance of low-cost adsorbent such as Neem leaves powder in the removal of Cadmium (II) and Lead (II) ion from aqueous solution is performed. It was found that the metal uptake capacity (amount of removal) of Cadmium (II) and Lead (II) ion decreased, but the adsorption capacity (percentage of removal) increased with the decrease in the concentration of Cadmium (II) and Lead (II) in the initial sample solution [36].

Ayub S. *et al.*, 2013, studied that the adsorption process has been recognized as an effective and economic method for the removal of heavy metals from wastewaters as it offers flexibility in design and operation so as to produce high quality treated effluents of desired standards for disposal and moreover the adsorbents can be regenerated by suitable desorption [37].

Sadaoui Z. *et al.*, 2013, studied on waste materials with no further treatment such as orange barks from commercial oranges may act as adsorbent for the removal of $Pb^{2+}$and the maximum adsorption capacity found was equal to 112,36 $mg.g^{-1}$ [38].

Wolfová R. *et al.*, 2013, the studied of nuts of European walnut (*Juglans regia*) arising as waste from the agricultural production for the removal of heavy metals from aqueous solutions [39].

Oluyemi E. A. *et al.*, 2012, studied at the removal of Pb^{2+} and Cd^{2+} ions from wastewaters using Palm Kernel Shell Charcoal (PKSC). The influence of several operating parameters such as the effects of adsorbent dose, time of contact of adsorbate with adsorbent, and agitation speed were investigated. The optimum found that the PKSC dose for cadmium and lead ions was 2.0 g/25mL of solution and the optimum shaking time were 45 and 50 min for cadmium and lead ions respectively [40].

Okafor P.C. *et al.*, 2012, studied explored the adsorption capacity of Coconut (*Cocos nucifera L.*) shell for Pb^{2+}, Cu^{2+}, Cd^{2+} and As^{3+} from aqueous solutions. It was found that coconut shell (CNS) can be used as a low cost adsorbent for the removal of heavy metals in aqueous solution containing low concentrations of the metals [41].

Nwabanne J. T. and Igbokwe P. K., 2012, studied on adsorption of lead(II) from wastewater effluents using indigenous cellulose based waste biomass, such as nipa palm nut (NPN), palmyra palm nut (PPN), oil palm empty fruit bunch (EFB), oil palm fibre (OPF), and oil palm shell (OPS), as potential raw materials for the preparation of activated carbons was Studied. The optimum pH was obtained at pH6 for all the adsorbents. It was found of adsorption studied showed that activated carbons produced from OPS and NPN are the most efficient adsorbents for the removal of Pb^{2+} from aqueous solutions [42].

T. O. *et al.*, 2012, *studied that* Blighia sapida pod was utilized as a low cost adsorbent to remove Pb(II), Cd(II) and Co(II) ions from aqueous solutions. It was found that maximum pH for Pb(II), Cd(II) and Co(II) ions removal from aqueous solution occurred at 6 [43].

Raju D. S. S. R. *et al.*, 2012, studied that Carica papaya leaf powder as the low-cost adsorbent was investigated as a replacement for cost effective methods of removing lead (II) ions from aqueous solutions. It was found that the optimum dosage of 1.5gm of carica papaya leaf powder of 52µm size was obtained to remove 89.8% of 100 mg/l concentration of Pb(II) from 50ml of aqueous solution in 1hour respectively [44].

Liu J. *et al.*, 2012, studied on Sesame leaf, an agricultural solid waste, was used as low cost adsorbent for removal of Pb(II) from aqueous solution in batch mode. The adsorption capacity of the biosorbent was found to be 279.86 mg g-1, which was higher or comparable to the adsorption capacity of various adsorbents reported in the literature [45].

Adelaja O. A *et al.*, 2011, studied of adsorption of Pb^{2+} onto ground Moringa oleifera pods was studied under various conditions such as, pH, contact time, adsorbent dosage, and concentration of adsorbate. It was found to be maximum percent adsorption obtained after contacting the Pb^{2+} aqueous solution with ground Moringa pods for 180 mins was 48.4% at pH 7. The study revealed that Moringa pod is not a very good biosorbent for the removal of Pb^{2+} from wastewater at PH [46].

Mondal N. K. and Das B., 2011, The studied that feasibility of employing calcareous soil to remove lead (II) ions from its aqueous solutions was investigated under batch mode. The lead adsorption was found to be favored with maximum adsorption at pH 6.0 and sorption equilibrium time was observed in 60 min [47].

Kuchekar S.R. *et al.*, 2011, studied at Lead pollution impacts all the systems of the human body. In investigated the phenol formaldehyde resin prepared from Tamarindous indica seeds. It was found to be 100% adsorption on 5 gm resin at 20 min [48].

Kumar U. and Acharya J., 2011, A new adsorbent material for removing lead ions from aqueous solutions had been investigated. Studied that the sorption of Pb(II) from aqueous solution on chemically pretreated rice husk. Equilibrium time was found to be 60 min. The activation energy for the sorption of Pb(II), was found to be 20.02 kJ/mol indicating chemisorptions [49].

Eba1 F.*et al.*, 2011, The research was undertaken to studied that the potential efficiency as adsorbents of three acid activated carbons, prepared from plant biomass of colas edulis shell (CAH), pentaclethra macrophylla husk (GAH) and aucoumea klaineana sawdust (QAH), for the removal of Pb (II) ions from aqueous solution, by the means of batch technique. The adsorption process was found to be realized spontaneously between 308 and 318K [50].

Mousavi H. Z. *et al.*, 2010, The studied was to investigate the possibility of the utilization of waste tire rubber ash (WTRA) as a low cost adsorbent for removal of lead (II) ion from aqueous solution [51].

Asandel D. *et al.*, 2009, The adsorption behaviour of lead (II) ions from aqueous solutions onto chitosan was investigated. Adsorption experiments were performed in a batch system, at room temperature (20 ± 0.5 °C), by changing the various experimental parameters: initial solution pH, chitosan dosage, initial lead (II) concentration and contact time. It was found that results the effectiveness of lead ions removal is mainly dependent on the initial concentration of lead ions to chitosan dosage ratio, which should be optimized by a compromise between the removal yield and cost-effectiveness of the process [52].

Sha L. *et al.*, 2009, Preparation of orange peel xanthate and its adsorption behaviors of five heavy metals (Cu^{2+}, Cd^{2+}, Pb^{2+}, Zn^{2+} and Ni^{2+}) were studied. It was found that the maximum adsorption capacities of Cu^{2+}, Cd^{2+}, Pb^{2+}, Zn^{2+} and Ni^{2+} were obtained as 77.60, 76.57, 218.34, 49.85 and 15.45 mg/g, respectively [53].

Qaiser S. *et al.*, 2009, The biosorption of lead(II) and chromium(VI) on groundnut hull was investigated. The maximum biosorption capacity of lead(II) and chromium(VI) was found to be 31.54 ± 0.63 and 30.21 ± 0.74 mg g^{-1}, respectively. The optimum pH for lead(II) and chromium(VI) removal was 5 ± 0.1 and 2 ± 0.1, respectively [54].

Wahi R. *et al*., 2009, The ability of activated carbon prepared from palm oil empty fruit bunches (EFB) to remove mercury (Hg(II)), lead (Pb(II)) and copper (Cu(II)) from aqueous solutions was investigated. The adsorption capacity was determined as a function of adsorbate initial concentration and adsorbent dosages [55].

Mengistie A. A. *et al*., (2008), The studied that adsorption of lead(II) on to activated carbon developed from an indigenous Ethiopian medicinal plant leaves namely Birbira (*Militia ferruginea*) was investigated to assess the possible use of this adsorbent. The adsorption followed the first order kinetics and was found to be pH dependent being maximum at pH 4.0 [56].

Chaghaby G. A. F. E. *et al*., 2007, The studied of removal of poisonous Pb (II) from wastewater by different low-cost abundant adsorbents was investigated. The adsorption efficiencies were found to be pH dependent, increasing 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 gm [57].

Omar W. and Itawi H. A., 2007, the studied of adsorption potential of the kaolinite clay for the removal of lead ions from aqueous solutions was tested. The measured adsorption isotherms at the different temperatures 298.15 K, 308.15 K and 318.15 K were found to be perfectly fit to the Langmuir isotherm equation [58].

Hashem M. A., 2007, studied at, Okra wastes from food canning processes were used as a potential adsorption of lead removal from various aqueous solutions was performed. The optimum pH for lead removal was between 4 and 6, the percentage of lead removal at equilibrium increases with increasing the amount of okra wastes and temperature. Better adsorption at higher temperatures. The removal of Pb^{2+} ions attained 99%., this means that Pb^{2+} can be effectively removed from aqueous solutions by okra wastes [59].

Yavuz O. *et al*., 2006, The removal of toxic cadmium(II) and lead(II) from aqueous solutions was investigated using calcite, which is inexpensive and widespread over the globe, as the effective inorganic adsorbent. The maximum adsorption capacities was found to be at 18.52 mg/g Cd and 19.92 mg/g Pb for natural calcite at 25°C, respectively [60].

Aziz H. A. *et al*., 2005, the studied was conducted to determine the removal efficiency of heavy metals (Ni, Cd, Pb and Zn) and colour from wastewater using cheap available materials in Malaysia such as charcoal, coconut shell carbon and a mixture of these carbons with limestone. It was found results that a mixture of activated carbon and limestone had removed 92% of heavy metals and 85% of colour from synthetic wastewater at a wide range of pH. When activated carbon was only used, 85% of heavy metals and 99% of colour were removed. For a mixture of charcoal with limestone, the removal efficiencies for heavy metals and colour were at 65% and 35%, respectively [61].

Conclusion

The present literature review study of various agro and horticultural adsorbents over here shows a great potential for the removal of lead from wastewater. The sorption capacity depends on the type of the adsorbent investigated and the nature of the wastewater treated as well. There is an urgent need of more detailed studies to be carried out so as to better understand the process of more effective and economic adsorption hence therefore to develop such a technology that matters truly and effectively.

Acknowledgement

The authors are thankful to Department of Chemical Engineering and Ujjain Engineering College, Ujjain (M.P.) for permission to collect literature from the library and their cooperation.

References

1. Ko DCK, Porter JF, Mckay G. Optimized Correlation for the Fixed Bed Adsorption of Metal Ions on Bone Char. Chemical Engineering Science 2000; 55:5819-5829.
2. Koller KBT, Spurgeon A, Levy L. Recent Development in Low Level Exposure and Intellectual Impairment in Children. Environmental Health Perspective 2004; 112:987-994.
3. National Research Council Canada Effect of Lead in the Canadian Environment, Report NRCC 16745, Ottawa, 1978.
4. Patterson, JW. Industrial Wastewater Treatment Technology. 2nd Edition, Butterworth Publishers, Stoneham, 1985.
5. Needleman HL. History of Lead Poisoning in the World. In: George, A.M., Ed., Lead Poisoning Prevention and Treatment: Implementing a National Program in Developing Countries, The George Foundation, Bangalore, 1999, 17-25.
6. Ademorati CMA. Environmental Chemistry and Toxicology. Foludex Press Ltd., Ibadan, 1996.
7. Schumann, K. The Toxicological Estimation of the Heavy Metal Content (Cd, Hg, Pb) in Food for Infants and Small Children. Zeitschrift für Ernährungswissenschaft 1990; 29:54-73.
8. Kazi TG, Jalbani N, Kazi N, Jamali MK, Arain MB, Afridi HI *et al.* Evaluation of Toxic Metals in Blood and Urine Samples of Chronic Renal Failure Patients, before and after Dialysis. *Renal Failure* 2008; 30:737-745.
9. Hinchee RE, Alleman BC. Hydrocarbon Bioremediation. CRC Press, Boca Raton, 1991.
10. Agarry SE, Ogunleye OO. Aworanti AO. Biosorption Equilibrium, Kinetic and Thermodynamic Modeling of Naphthalene Removal from Aqeous Solution onto Modified Spent Tea Leaves. *Environmental Technology* 2013; 34:825-839.
11. Ozcan A, Ozcan AS. Adsorption of Acid Red 57 from Aqueous Solutions onto Surfactant Modified Sepiolite. Journal of Hazardous Materials 2005; 125:252-259.
12. Babarinde NAA, Babalola JO, Sanni RA. Biosorption of Lad Ions from Aqueous Solution by Maize Leaf. International Journal of Physical Sciences 2006; 1:23-26.
13. Oboh OI, Aluyor EO. The Removal of Heavy Metal Ions from Aqueous Solution Using Sour Sop Seeds as Biosorbent. African Journal of Biotechnology 2008; 7:4508-4511.
14. Egila JN, Okorie EO. Influence of pH on the Adsorption of Trace Metals on Ecological and Agricultural Adsorbents. Journal of Chemical Society of Nigeria 2002; 27:95-98.
15. Gimba CE, Olayemi JY, Ifijeh DOH, Kagbu JA. Adsorption of Dyes by Powdered and Granulated Activated Carbon from Coconut Shell. Journal of Chemical Society of Nigeria 2001; 26:23-27.
16. Upatham ES, Boonya B, Kriatracjie M, Pokethitiyook P, Park K. Biosorptionof Cadmium and Chromium in Duck

weed Wolffia globosa. International Journal of Phytoremediation 2002; 4:73-86.
17. Abdel-Ghani NT, Hefny M, El-Chaghaby GAF. Removal of Lead from Aqueous Solution Using Low-Cost Abundantly Available Adsorbents. International Journal of Environmental Science and Technology 2007; 4:67-73.
18. Ho YS, Huang CT, Huang HW. Agricultural By-Products as a Metal Sorbent: Sorption of Copper Ions from Aqueous Solution onto Tree Fern. *Process Biochemistry* 2002; 37:1421-1430.
19. Egila JN, Dauda BEN, Iyaka YA, Jimoh T. Agricultural Waste as a Low Cost Adsorbent for Heavy Metal Removal from Wastewater. International Journal of Physical Sciences 2011; 6:2152-2157.
20. Bello OS, Ahmad MA. Adsorptive Removal of a Synthetic Textile Dye Using Cocoa Pod Husks. Toxicological and Environmental Chemistry 2011; 93:1298-1308.
21. Gardea-Torresdey J, Hejazi M, Tiemann K, Parsons JG, Duarte-Gardea M, Henning J. Use of Hop (*Humulus lupulus*) Agricultural By-Products for the Reduction of Aqueous Lead(II) Environmental Health Hazards. Journal of Hazardous Materials 2002; 91:95-112.
22. Li X, Tang Y, Xuan Z, Liu Y, Luo F. Study on the Preparation of Orange Peel Cellulose Adsorbents and Biosorption of Cd2+ from Aqueous Solution. Separation and Purification Technology 2007; 55:69-75.
23. Amir HM, Darush N, Forugh V, Sharokh N. Tea Waste as an Adsorbent for Heavy Metal Removal from Industrial Wastewaters. American Journal of Applied Science 2005; 2:372-375.
24. Medeios RG, Scoffner MLAP, Thome JA, Cacais AOG, Estelles RS, Salles BC *et al.* The Production of Hemicelluloses by Aerobic Fungi on Medium Containing Residue of Banana Plants as Substrate. *Biotechnology Progress* 2000; 16:522-524.
25. Bello OS, Ahmad MA, Ahmad N. Adsorptive Features of Banana (*Musa paradisiaca*) Stalk-Based Activated Carbon for Malachite Green Dye Removal. *Chemistry and Ecology* 2012; 28:153-167.
26. Volesky B. Biosorption and Biosorbents. In: *Biosorption of Heavy Metals*, CRC Press, Boca Raton 1990, 3-5.
27. Ahalya N, Ramachandra TV, Kanamadi RD Dec. *Review Paper:* Biosorption of Heavy Metals. Research Journal of Chemistry and Environment 2003; 7(4):71-78.
28. Jeyakumar RPS, Chandrasekaran V. Adsorption of lead(II) ions by activated carbons prepared from marine green algae: Equilibrium and kinetics studies.International Journal of Industrial Chemistry 2014; 5:2.
29. Abou EMWM, El-Wakil AM, Awad FS. Removal of Lead from Aqueous Solution on Activated Carbon and Modified Activated Carbon Prepared from Dried Water Hyacinth Plant. J Anal Bioanal Tech 2014; 5:2.
30. Ghorbani1 A, Nazarfakhari M, Pourasad Y, Abbasi SM. Removal of Pb ion from water samples using red mud (bauxite ore processing waste). Published by EDP Sciences, 2014.
31. Murthy RC, Pandey R, Ansari1 NG, Prasad RL. Pb(II) Removal from Aqueous Solution by Cucumissativus (Cucumber) Peel: Kinetic, Equilibrium & Thermodynamic Study. American Journal of Environmental Protection 2014; 2(3):51-58.
32. Seniunait J., Vaiškunait R. and Bolutien May Vilnius, Lithuania. Coffee grounds as an adsorbent for copper and lead removal form aqueous solutions.The 9th International Conference "ENVIRONMENTAL ENGINEERING". 2014, 22-23.
33. Sujatal K, Singh D, Mishra AK, Upadhyay M, Saroj K. July Red Mud as Adsorbent to Remove Lead (II) from Aqueous Solutions". Research Journal of Recent Sciences 2014; 3(7):18-27.
34. Singha DK, Yadava SK, Sinhab S. April Removal of Lead(II) from Aqueous Solution using Papaya Seed Carbon: Characteristics and Kinetics Study.International Journal of Chemical and Environmental Engineering 2013; 4(2).
35. Tahiruddin NSM, Rahman SZA. July Adsorption of Lead in Aqueous Solution by A Mixture of Activated Charcoal and Peanut Shell. World Journal of Science and Technology Research 2013; 1(5):102-109.
36. Pandhare GG, Trivedi N, Rajesh Pathrabe R, Dawande SD. October Adsorption Of Cadmium (II) And Lead (II) From A Stock Solution Using Neem Leaves Powder As A Low-Cost Adsorbent. International Journal of Innovative Research in Science, Engineering and Technology 2013, 2(10).
37. Ayub S, Sharma PK, Tripathi CN. August Agro and Horticultural Wastes as Low Cost Adsorbents for Removal of Heavy Metals from Wastewater: A Review. International Refereed Journal of Engineering and Science (IRJES) ISSN (Online) 2319-183X 2013; 2(8):18-27.
38. Sadaoui Z, Azouaoua N, Belmedanib M, Mokaddema H. Adsorption Of Lead From Aqueous Solution Onto Untreated Orange Barks.A Publication Of The Italian Association Of Chemical Engineering, Chemical Engineering Transactions, 2013, 32.
39. Radka Wolfová R, Pertile E, Fečko P. June Removal of lead from aqueous solution by walnut shell. Journal of Environmental Chemistry and Ecotoxicology 2013; 5(6):159-167.
40. Oluyemi EA, Adeyemi AF, Olabanji IO. Removal of Pb^{2+} and Cd^{2+} Ions from Wastewaters Using Palm Kernel Shell Charcoal. Research Journal in Engineering and Applied Sciences, 2012, 308-313.
41. Okafor1 PC *et al.*, Adsorption Capacity of Coconut (Cocos nucifera L.) Shell for Lead, Copper, Cadmium and Arsenic from Aqueous Solutions. International Journal of Electrochemical Science, 2012, 7.
42. Nwabanne JT, Igbokwe PK. July-August Comparative Study of Lead (II) Removal from Aqueous Solution Using Different Adsorbents.International Journal of Engineering Research and Applications (IJERA) 2012; 2(4):1830-1838.
43. Jimoh TO *et al.*, July Utilization of *Blighia sapida* (Akee apple) pod in the removal of lead, cadmium and cobalt ions from aqueous solution. Journal of Environmental Chemistry and Ecotoxicology 2012; 4(10):178-187.
44. Raju DSSR, Rao VN, Prasad PR, Babu NC. Sorption of Lead (Ii) Ions from Wastewater Using Carica Papaya Leaf Powder. International Journal of Engineering Science & Advanced Technology 2012; 2(6):1577-581.
45. Liu J, Liu L, Li H, Zhang H, Liu J, Zhang H. Equilibrium, Kinetic And Thermodynamic Studies Of Lead (II), Biosorption On Sesame Leaf. Resources 2012, 7(3).
46. Adelaja OA, Amoo IA, Aderibigbe AD. Biosorption of Lead (II) ions from aqueous solution using *Moringa oleifera* pods. Scholars research library Archives of Applied Science Research, 2011.
47. Mondal NK, Das B. Calcareous Soil as a New Adsorbent to Remove Lead from Aqueous Solution: Equilibrium,

Kinetic and Thermodynamic Study". Universal Journal of Environmental Research and Technology All Rights Reserved Euresian Publications 2011; 1(4):515-530.

48. Kuchekar SR, Gaikwad VB, Sonawane DV, Lawande SP. Adsorption of Pb (II) ions on Tamarindous indica seeds as a low cost abundantly available natural adsorbent. Pelagia Research Library Der Chemica Sinica, 2011.
49. Kumar U, Acharya J. December Thermodynamics of the Sorption of Pb(II) from Aqueous Solution on NCRH. International Journal of Chemical Engineering and Applications 2011; 2(6).
50. Eba1 F, Nlo JN, Biboutou RK, Menye Biyogo R RM, Engonga PE, Reonignaud H *et al.* Removal of Pb (II) in aqueous solution using acid activated carbons prepared from cola edulis shell (Alocaceae), pentaclethra macrophylla husk (Mimosaceae) and aucoumea klaineana sawdust (Burseraceae). African Journal of Pure and Applied Chemistry 2011; 5(8):245-254.
51. Mousavi1 HZ, Hosseynifar1 A, Jahed V, Dehghani SA, M. January – March, Removal Of Lead From Aqueous Solution Using Waste Tire Rubber Ash As An Adsorbent. Brazilian Journal of Chemical Engineering 2010; 27(01):79-87.
52. Asandei D, Bulgariu L, Bobu E. Lead (II) Removal from Aqueous Solutions by Adsorption onto Chitosan. Cellulose Chemistry and Technology, 2009.
53. Sha L, Yi GX, Chuan FN, Hua TQ. Effective removal of heavy metals from aqueous solutions by orange peel xanthate. Elsevier Press Trans. Nonferrous Met. Soc. China, 2010, S187-S191
54. Qaiser S, Saleemi AR, Umar M. Issue of October 15, Biosorption Of Lead(II) And Chromium(VI) On Groundnut Hull: Equilibrium, Kinetics And Thermodynamics Study. Electronic Journal of Biotechnology, 2009; 12(4).
55. Wahi R, Ngaini Z, Jok VU. Removal of Mercury, Lead and Copper from Aqueous Solution by Activated Carbon of Palm Oil Empty Fruit Bunch. World Applied Sciences Journal 5 (Special Issue for Environment), 2009 84-91.
56. Mengistie AA. Removal Of Lead(Ii) Ions From Aqueous Solutions Using Activated Carbon From *Militia Ferruginea* Plant Leaves. Bull. Chem. Soc. Ethiop 2008; 22(3):349-360.
57. Hefny M, Ghani NTA, Chaghaby GAFE. Removal of lead from aqueous solution using low cost abundantly available adsorbents. Int. J. Environ. Sci. Tech, 2007.
58. Omar W, Itawi HA. Removal of Pb^{+2} Ions from Aqueous Solutions by Adsorption on Kaolinite Clay. American Journal of Applied Sciences, 2007; 4(7).
59. Hashem MA. July, Adsorption of lead ions from aqueous solution by okra wastes. International Journal of Physical Sciences 2007; 2(7):178-184.
60. Yavuz Ö, Guzel R, Aydin F, Tegin I, Ziyadanogullari R. Removal of Cadmium and Lead from Aqueous Solution by Calcite. Polish J. of Environ. Stud 2006, 16(3).
61. Aziz HA, Adlan MN, Hui CS, Zahari MSM, Hameed BH. June Removal of Ni, Cd, Pb, Zn and colour from aqueous solution using potential low cost adsorbent.Indian Journal of Engineering & Materials Sciences 2005; 12:248-258.