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Full Length Research Paper

Utilization of biomaterials as adsorbents for heavy metals' removal from aqueous matrices

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Globally, the available amount of freshwater is unevenly distributed due to problems associated with climate change, inefficient water management and pollution. This has led to increased demand for water worldwide. Heavy metals, in particular are a group of pollutants (mostly from domestic, agricultural and industrial activities) of major concern in the aquatic environment due to their toxicity. Existing technologies for heavy metals' removal from waters and wastewaters are often ineffective (especially at environmental levels), expensive and unavailable in developing countries. A higher percentage of these pollutants are therefore being released into aquatic ecosystems by manufacturing facilities in these nations. The need to find alternative inexpensive and effective methods for heavy metals abatement from waters becomes inevitable. Biosorption is an emerging field in this regard and has great potentials for application in developing economies. It involves the use of living or non-living biological materials for pollutants' removal from aqueous solutions and industrial effluents. This paper therefore reviews developments in the use of biosorbents for the remediation of waters and wastewaters.

Key words: Heavy metals, waters and wastewaters, biosorption, pollution.

INTRODUCTION

An increased use of metals and chemicals in the process industries has resulted in the generation of large quantities of aqueous effluents that contain high levels of heavy metals, thereby creating serious environmental disposal problems (Antunes et al., 2003). Also exponential growth of the world's population over the past 20 years has resulted in environmental build up of waste products, of which heavy metals are of particular concern (Appel and Ma, 2002). Heavy metals, which are not biodegradable (Vijayaraghavan et al., 2004) are therefore of great concern because they are being added to soil, water and air in increasing amounts. Some, for example, copper, manganese and zinc are micro nutrients though essential in small amounts for plant and animal life, can however be harmful if taken up by plants or animals in large amounts, like other heavy metals not known to be essential nutrients (Alan, 1994).

Increased knowledge about eco-toxicological effects of heavy metals as well as increased legal requirements for reduction in industrial emissions necessitates research and development in the area of wastewater treatment. Since heavy metals accumulate in the food chain and because of their persistent nature, it is necessary to remove them from wastewater (Cossich et al., 2002; Klimmek et al., 2001). The need for economical and effective methods for removing heavy metals from wastewater has therefore resulted in the search for other materials that may be useful in reducing the levels of heavy metals in the environment (Okieimen et al., 1991).

Existing technologies for metal ion removal from wastewaters are costly. They include ion exchange resin, solvent extraction, electrolytic and precipitation processes, electrodialysis and membrane technology (Stirk

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and Staden, 2000). Other conventional technologies which have also been used ranged from granular activated carbon to reverse osmosis. These processes are however, not economically feasible for small scale industries prevalent in developing economies due to large capital investment (Horsfall and Spiff, 2004). Precipitation processes which are the most widely used techniques for treating wastewater with high metal concentrations often results in the production of large volumes of sludge containing high levels of heavy metals. Thus, additional treatment such as ion exchange, reverse osmosis or adsorption processes are required in order to purify the effluent prior to discharge (Ulmanu et al., 2003).

Since most conventional methods are neither effective nor economical, especially when used for the reduction of heavy metal ions to low concentrations, new separation methods are required to reduceheavy metal concentrations to environmentally acceptable levels at affordable cost. Bio-removal has the potential to contribute to the achievement of this goal (Klimmek et al., 2001; Addour et al., 1999; Al-Asheh and Duvnjak, 1999). Bio-removal is the accumulation and concentration of heavy metals from aqueous solutions using biological materials (Stirk and Staden, 2000). Metals removal has been achieved by adsorption on different materials such as activated carbon, agricultural waste, moss peat, minerals, amongst others (Shukla and Pai, 2005). In Nigeria, Okieimen et al. (1991), Horsfall and Spiff (2004) and Horsfall et al. (2003) have used groundnut husk, fluted pumpkin and wild cocoyam respectively for removal of heavy metals from aqueous solutions.

The term, biosorption is used to describe the passive non- metabolically mediated process of metal binding to living or dead biomass (Rangsayatorn et al., 2002). Biosorption of heavy metals from aqueous solutions can be considered as an alternative technology in industrial wastewater treatment. The technique is an emerging technology based on the ability of biological materials to accumulate heavy metals from wastewater by either metabolically mediated or physico – chemical pathways of uptake (Antunes et al., 2003; Kaewsarn and Yu, 2001).

A variety of low-cost biomass has been developed and commercialized for controlling pollution from diverse sources in different parts of the world (Kar and Misra, 2004). They include anaerobically digested sludge (Tokcaer and Yetis, 2006), bacteria (Lu et al., 2006), fungi (Garcia et al., 2005) and algae (Elifantz and Tel-Or, 2002). Agricultural materials have also been used. These include rice bran, soybean and cottonseed hulls (Marshall and Johns, 1996), crop milling waste (Saeed et al., 2005), groundnut husk (Okieimen et al., 1985), maize cob meal (Okieimen and Okundaye, 1989), coir, jute and sawdust (Shukla and Pai, 2005), canola meal (Al-Asheh and Duvnjak, 1999), and coconut shell (Ogunsuyi et al., 2001) amongst others.

Biosorption uses inexpensive dry biomass to extract toxic heavy metals from industrial effluents. The biomass can be shredded or ground to yield stable biosorbent particles. Alternatively, it can be immobilized by a synthetic polymer or fixed onto an inorganic support material. The biosorbent particles can be packed in columns which are the most effective devices for continuous removal of heavy metals. Once the metal binding reaches saturation, the biomass can be regenerated with acid and/or hydroxide solutions, which discharge small volumes of concentrated heavy metal. The advantages of biosorption are low operating costs, minimal volumes of chemical disposal and/or biological sludge and high efficiency in detoxifying very dilute effluents. These advantages constitute the primary incentives for developing full-scale biosorption processes for the removal of heavy metals from contaminated solutions (Klimmek et al., 2001).

The use of dead biomass is of particular economic interest, because the biomaterials are used the same way as synthetic adsorbents or ion exchangers and repeated regeneration is possible (Klimmek et al., 2001). Biosorption has been found to be a more rapid mechanism; hence, it has a more significant role in metal sorption from wastewater. Biological treatment processes for removing heavy metals from wastewater are most effective when contaminant concentrations are below and above 100 mg/L (Rangsayatorn et al., 2002).

Activated charcoal

The large surface area, micro-porous character and chemical nature of the surface of activated charcoals have made them potential adsorbents for the removal of heavy metals form industrial wastewaters (Demirbas et al., 2004). Kadirvelu and Namasivayam (2003) used activated carbon from coconut coir pith as a metal adsorbent. Activated carbon from coconut coir pith which is an agricultural solid waste by-product was used for the adsorption of Cd (II) from aqueous solution. Parameters such as agitation time, metal ion concentration, adsorbent dose and pH were studied. The charcoal effectively removed Cd (II) from aqueous solutions. Mechanism for adsorption seems to be ion exchange. As coirpith was being discarded from coir processing industries, the carbon is expected to be an economical product for metal ion remediation from water and wastewater.

Bose et al. (2002) evaluated treatment strategies involved in the use of three adsorbents (sulphonated coal, biosorbent *Ganoderma lucidum* and iron oxide coated sand), and a chelating agent, insoluble agro-based starch xanthate. Evaluation procedure involved comparison of the performance of these treatment strategies with conventional treatment. The three adsorbents tested were reported to be very effective in removing copper and zinc from pure systems, though with diminished metal removal capacity in the presence of cyanide.

The sorption of copper and cadmium ions using activated carbon and other waste materials as adsorbents was reported by Ulmanu et al. (2003). Of all the materials studied, bentonite, compost and anaerobic sludge exhibited better adsorption capacities, the lowest residual concentrations, and therefore the greatest removal capacities of the metals.

Activated carbon prepared from peanut hulls, an agricultural waste by-product has been used for the adsorption of cadmium from synthetic wastewater. Peanut hull carbon was found to be an effective adsorbent for the removal and recovery of Cd (II) from aqueous solutions; its adsorption capacity being much superior to commercial activated carbon (Periasamy and Namasivayam, 1994). Similarly, activated carbons were used for the removal of Cr (VI) effectively from aqueous solutions with a percentage removal of up to 99.99% Cr (VI) at 25°C. Adsorption of Cr (VI) was highly pH-dependent (Demirbas et al., 2004).

Chitosan coated oil palm shell charcoal was used for the removal of heavy metals from industrial wastewater. The research focused on understanding biosorption process and developing a cost effective technology for treatment of industrial wastewaters contaminated with heavy metals. The study showed that the use of chitosan coated oil palm shell charcoal for metal ion removal appears to be technically feasible, eco-friendly and with high efficacy (Nomanbhay and Palanisamy, 2005).

Although, the efficacy of activated carbon as adsorbents for heavy metals from wastewater is high enough, significant costs involved in its preparation and regeneration limits its use only at the tertiary step in the treatment of wastewaters.

Algae, bacteria and fungi

The accumulation of metals by algae, bacteria, fungi and yeast has been extensively studied in the last two decades and its application in the treatment of metal and humus containing water (Zhou et al., 1998). There are three general categories that describe the biological process of removing metal ions from solution. They include biosorption of metal ions onto the surface of a microorganism, intracellular uptake of metal ions and chemical transformation of metal ions by microorganisms.

Of the microorganisms studied, algae are gaining increasing attention, due to the fact that algae, particularly, marine algae are a rich resource in the oceanic environment, relatively cheap to process and able to accumulate high metal contents (Yun et al., 2001). Unlike microorganisms, the size of seaweed biomass is large enough to facilitate its application without a cumbersome solid-liquid separation process. Adsorption on cell surfaces is the dominant mechanism; both surface adsorption and internal diffusion are involved in the uptake of metals by algae (Zhou et al., 1998). Some advantages of the use of dead cells include metal removal system is not subjected to metal toxicity limitations, no requirement for growth media and nutrients, easy desorption of metals from biomass, and the possibility of biomass re-use (Klimmek et al., 2001).

Furthermore, in a dead biomass-based sorption system, where there are no metallic interactions, they can be subjected to conventional theories and mathematical models already in place for traditional adsorption systems (Romero-Gonzalez et al., 2001).

Apart from marine algae, microbial, fungal, yeast and microalgal biomasses have also been widely investigated and found to provide efficient systems for accumulating metals. Microalgal biomasses have the advantage that they are relatively easy to grow and produce in large quantities; however, the medium, age, and growth phase of the culture influence the metal binding efficiency of algae. Another potential problem is that growth and bioremoval efficiency of microalgal biomass may be limited by toxic effects of heavy metals in solution (Stirk and Staden, 2000).

The potential of *Ulva reticulata*, a marine algae, to remove copper (II) from aqueous solutions under different environmental conditions was studied by Vijayaraghavan et al. (2004). Adsorption capacity of the algae was reported to have increased with increase in pH; equilibrium adsorption data was found to agree with Freundlich's isotherm model with high correlation coefficients. Also, adsorption properties of a pre-treated biomass from marine alga *Padina* sp. for removal of cadmium (II) ions from aqueous solutions were investigated by Kaewsarn and Yu (2001). They demonstrated that the pre-treated biomass of *Padina* sp. could be used as an efficient biosorbent for the treatment of cadmium (II) - bearing wastewater streams. Thirty strains of algae were examined for their biosorption abilities in the uptake of cadmium, lead, nickel and zinc from aqueous solutions (Klimmek et al., 2001). A wide range of adsorption capacities between the different strains of algae and between the four metals were observed. Metal binding capacities were influenced by chemical modification of the biomass. Antunes et al. (2003) and Cossich et al. (2002) carried out studies to evaluate copper and chromium biosorption respectively from aqueous solutions by a brown seaweed *Sargassum* sp. under optimized conditions. *Sargassum* sp. was proved to be an excellent biomaterial for accumulating and recovering copper and chromium from solutions.

The potential of two aquatic macrophytes for cadmium and chromium removal from solution was investigated by Sune et al. (2007). They established that metal removal from solution involves two stages: A fast one and a slow one. Some of the processes identified for metal uptake include chelation, ion exchange and precipitation. Adsorption features of *Cladophora fascicularis* were investigated as a function of time, initial pH, initial Pb (II) concentrations, temperature and co-existing ions. The study indicated that the green marine algae, *C. fascicularis* can be used as an efficient biosorbent material for removal of Pb (II) from wastewater (Deng et al., 2007).

Lu et al. (2006) investigated biosorption kinetics and equilibria of lead, copper and cadmium ions using the biomass of *Enterobacter* sp. J1 isolated from a local industry wastewater treatment plant. Efficiency of metal ion recovery from metal-loaded biomass to regenerate the biosorbent was also determined. The bacterial isolate exhibited good metal uptake capacity and high resistance to various heavy metals. Hussein et al. (2004) studied biosorption of heavy metals from wastewater using *Pseudomonas* sp. Metal removal was reported to increase with increasing influent flow.

In a study that examined the possibility of using *Spirulina platensis* TISTR 8217 to remove low concentrations of cadmium from wastewaters, some environmental factors which include pH were found to have an effect on biosorption while cadmium uptake was not affected by solution temperature. Both living and dead cells of *S. platensis* have high tolerance to cadmium, so it can be effectively applied to remediate wastewaters (Rangsayatorn et al., 2002). Ilhan et al. (2004) studied selective biosorption of chromium, lead and copper ions from industrial wastewaters using *Staphylococcus saprophyticus*. They concluded that *S. saprophyticus* can be used in the removal or recovery of lead and chromium ions from industrial wastewaters.

Streptomyces rimosus biomass, an antibiotic production waste material was used to bind Zinc (II) ions from an industrial wastewater. Biomass pretreatment with sodium hydroxide improved its Zinc (II) binding capacity (Addour et al., 1999). Heavy metal adsorption capacity of a waste product from the manufacture of the seaweed concentrate made from *Ecklonia maxima* was tested to determine its heavy metal adsorption capacity by Stirk and Staden (2000). All the algal biomasses tested were able to sequester ions from solutions effectively suggesting that there is potential to develop this for industrial purposes.

The effects of different nutrient conditions on the biosorption ability and selectivity of heavy metals by *Saccharomyces cerevisiae* was investigated by Engl and Kunz (1995). The study showed that the heavy metal biosorption capacity of *S. cerevisiae* is influenced by nutrient conditions and that selectivity of metal uptake can be obtained by varying the nutrient conditions. Furthermore, Han et al. (2006) showed that waste beer yeast, a by-product of brewing industry is a low cost and promising adsorbent for copper and lead ions from wastewater. The amount of one metal ion adsorbed onto unit weight of biosorbent decreased with increasing competing ion concentration. Ion exchange was reported to be probably one of the main mechanisms for adsorption.

Fungi growing in urban and industrial environments often show high concentrations of toxic heavy metals.

Some species show high metal concentrations even in non-contaminated areas; some have been reported to show high cadmium levels in rural areas, suggesting that this may be a physiological characteristic independent of environmental contamination. The bioaccumulation of heavy metals by fungi has attracted research attention in view of possible health risks for consumers of cultivated or wild edible mushrooms, but also, in view of the potential application of fungi for bioremediation purposes (Garcia et al., 2005; Kar and Misra, 2004).

The ability of mycelia of *Rhizopus delemar* (both free and immobilized on polyurethane foam) to remove heavy metals from single ion solutions as well as a mixture of them was studied by Tsekova and Petrov (2002). The results showed that immobilized mycelia of *R. delemar* can be used repeatedly for the removal of heavy metals from aqueous solutions. Studies on the feasibility of *Aspergillus flavus* biomass as a biosorbent to remove cadmium, lead and zinc from their solutions were carried out by Kok et al. (2001). The authors showed that uptake of cadmium, lead and zinc were chemical, saturable and equilibrated mechanism because experimental data fitted well into Langmuir Isotherm Model. The data also reflected that multiple binding sites were involved in cadmium, lead and zinc biosorption by biomass of *A. flavus*.

Different microbial biomass types have been chemically modified and used for metal sorption or recovery studies. Leusch et al. (1995) processed raw biomass with chemicals in order to reinforce it for sorption process applications and also to enhance adsorbent performance. Metal biosorption is however, reported to be generally decreased by chemical modification of biomass.

Algae, fungi and bacteria seem to be the group most extensively studied by researchers; this has led to curiosity by scientists to explore agricultural by-products for heavy metals' removal from waters. Emphasis is being shifted now to investigating animal and plant (cellulosic) waste materials for heavy metals remediation.

Animals by-products

Ogunsuyi et al. (2006) investigated the potential of oyster shell alongside with maize cob and coconut shell to remove copper ions from solution. Experimental data for the three adsorbents fitted well only to the Freundlich's Isotherm Model. Oyster shell powder showed the greatest potential for copper ion sorption from solution out of the three adsorbents studied.

Also, the adsorption potentials of oyster and giant snail shells have been demonstrated by Ajayi et al. (2005). The two adsorbents were effective in adsorbing up to 90% of Pb^{2+} from solution and adsorption patterns indicated chemisorption mechanism and possible utilization of the materials for the remediation of waste waters contaminated with heavy metals.

Kar and Misra (2004) studied the ability of keratin fibre to remove heavy metals from solutions; high tensile strength and water insolubility were reported to make the keratin fibre attractive for biosorption. Furthermore, stability over a wide range of pH, structural toughness and high surface area, are positive factors for adsorption by keratin fibre.

Studies on the use of animal by-products as adsorbents for heavy metals is however sparse; probably because such products often have useful applications thereby reducing availability for wastewater remediation.

Cellulose- based materials

Cellulosic materials and their derivatives have shown quite good metal ion adsorptive capacity. Although, the efficiency of activated carbon in adsorbing heavy metal ions from wastewater is high enough, because of significant costs involved in preparation of activated carbon and its regeneration, it is only used as a tertiary step in the treatment of wastewater. Among all the heavy metal removal techniques reported so far, ion exchange technique using cellulose-based agricultural waste products appears to be most attractive since it is an effective and relatively simple method for removal of heavy metal ions. Also, the adsorption capacity is reduced at every stage of regeneration (Shukla and Pai, 2005).

The seaweed biomass has been used for biosorption research and has been confirmed to be a good biosorbent for removal of various heavy metal ions. Furthermore, many kinds of seaweed proliferate ubiquitously and abundantly in the littoral zones of the world's oceans, making the seaweed biomass readily available and inexpensive (Yun et al., 2001). Elifantz and Tel-Or (2002) tested root biomass, floating roots and leaves of *Ludwigia stolonifera* for their performance as heavy metal biofilters. There were differences in metal binding to the different plant parts which suggest that there might be differences in the composition of binding groups in the cell walls of each part. Possible mechanisms of metal uptake include ion exchange with H^+ and light metals or through coordinated bonding.

The ability of sawdust to adsorb chromium from waste solutions was investigated by Zarraa (1995), who used a batch reactor under forced convection conditions. Variables investigated included rotational speed of the impeller, initial concentration of Cr (VI) in solution and the weight and particle diameter of sawdust. Increasing both rotational speed of the impeller and the initial concentration of chromium in solution led to an increase in the volumetric mass transfer coefficient.

Dakiky et al. (2002) also removed Cr (VI) from industrial waste water by different low-cost abundant adsorbents. Wool, olive cake, sawdust, pine needles, almond shells, cactus leaves and charcoal were used at different adsorbent/metal ion ratios. The influence of pH, contact time, metal concentration, adsorbent nature and concentration on the selectivity and sensitivity of the removal process was investigated.

The sorption of lead on sawdust has been studied by using batch techniques (Yu et al., 2001). Lead sorption was reported to be a function of the solution pH, contact time, sorbent and sorbate concentration. Results indicated that sawdust has potential practical value in heavy metal removal from wastewaters. The use of sawdust for the removal and recovery of heavy metals is reported to be potentially more economical than current process technology (Prasad and Freitas, 2000).

Al – Subu (2002) also carried out batch and isotherm studies to compare the effectiveness of decaying leaves of cypress, cinchona and pine to adsorb lead from its aqueous solution and to study the leaf interaction effects. Lead removal was reported to increase with increasing concentrations of both lead ions and the plant leaves employed. The adsorption of lead by cypress and cinchona leaves was well defined by both Freundlich and Langmuir isotherms, but only Freundlich isotherm was adopted for pine leaves. Brown et al. (2000) also assessed the potential of peanut hulls and a commercial grade ion exchange resin to remove metal ions from wastewater. Peanut hull pellets were reported to be an effective adsorbent for metal ion removal. Cd (II) and Pb (II) ions were removed from aqueous solutions using EDTA modified groundnut husk in a study carried out by Okieimen et al. (1991). The study revealed that rate of adsorption was particle diffusion controlled.

The ability of cassava waste biomass to remove copper (II) and zinc (II) from single ion solution and wastewater was investigated by Horsfall et al. (2003). Metal ion uptake capacities in wastewater were found to be lower in single ion solution while uptake capacities of the metals on the biomass surface increased with acid treatment. Horsfall and Spiff (2004) also investigated the use of a non- useful plant material as naturally occurring biosorbent for the removal of Pb^{2+} and Cd^{2+} from wastewater. Surface characterization of acid and base treated *Caladium bicolor* biomass indicated that the predominant mechanism for sorption process includes physiosorption and the thermodynamic assessment of the metal ion on *C. bicolor* biomass system which indicated the feasibility and spontaneous nature of the process.

Furthermore, the ability of fluted pumpkin waste biomass to remove some divalent transition metal ions from aqueous solutions has been investigated (Horsfall and Spiff, 2005b). The study revealed that the four metals studied have different sorption potentials on fluted pumpkin biomass probably due to the presence of low and high affinity functional groups on the biomass. Ionic radii as well as the softness and hardness of metals and biomass surface could be largely responsible for the intensity of interaction in the adsorption process (Horsfall and Spiff, 2005b). The ability of pure and thioglycollic acid modified Nipah palm (*Nypa fruticans* Wurmb) petiole biomass to remove lead (II) from aqueous solutions has also been studied (Wankasi et al., 2005a; Wankasi et al., 2005b). Lead (II) adsorption was favoured by low metal concentration. However, for either pure-metal or modified-metal biomass systems, chemical reactions are important and significant in the rate controlling step.

The aerial roots of *Rhizophora mangle* was used in both its unmodified and modified forms for the sorption of Pb^{2+} from aqueous solutions (Horsfall et al., 2005). The waste materials from the aerial parts of *R. mangle* either chemically modified or not were assessed to be effective, inexpensive biosorbent for the removal of Pb (II) ions from aqueous solutions. The sorption process seems to be mainly based on rapid ion exchange taking place on the surface of the biomass cell wall.

The potential of cheap cellulose- containing natural materials which include coir, sawdust and groundnut shells for removal of Pb^{2+} from aqueous solutions was assessed before and after modification with a type of dye by Shukla and Pai (2005). Enhanced adsorption capacities were shown by the materials due to dye loading through chelation and ion exchange mechanisms.

Mahvi et al. (2005) studied the removal of cadmium, lead and nickel from industrial wastewaters using tea waste as adsorbent. Analysis of the experimental data indicated that tea waste like most other biosorbents can be used in the treatment process of heavy metals and the treatment efficiency may be as high as 100% by precise choosing of adsorbent amount. Treatment efficiency may also be enhanced by pre-treatment with some chemicals such as acids, bases and detergents.

The bark of *Hemidesmus indicus* was used as biomaterial for removal of lead from aqueous streams by Sekhar et al. (2004). The characterization of lead uptake by *H. indicus* showed that binding kinetics is pH dependent up to pH 5.0 and occurs in less than 5 min. Lead ion binding is on the cell wall and lead may be recovered remarkably by treatment with low concentration of nitric acid.

The removal of Pb (II) and Cd (II) from aqueous solutions by olive cake has been investigated. Olive cake has an aromatic ring containing a large number of hydrogen bonds with high content of phenolic components and prevalence of labile methoxy groups. These functional groups are known as excellent binding sites as well as cation exchange sites for heavy metals (Doyurum and Celik, 2006).

Garcia et al. (2005) reported that 10 $mgkg^{-1}$ Pb^{2+} was present in the compost used for an experimental culture. Also, different materials with similar concentration range have been reported in the literatures (Zhou et al., 1998; Ulmanu et al., 2003; Okieimen et al., 1985; Altin et al., 1999). Horsfall and Spiff (2005b) however used fluted pumpkin (*Telfaria occidentalis*) biomass for Pb^{2+} removal. Horsfall and Spiff (2005a) also used *C. bicolor* (wild cocoyam) biomass for sorption of Pb^{2+} and Cd^{2+} from 10 - 100 mgL^{-1} aqueous solutions. By implication, application of biosorption for heavy metal removal from aqueous solutions is feasible for a wide range of concentrations from low to high metal concentrations.

Okieimen et al. (1991) also reported that rate of removal of Cd (II) and Pb (II) from aqueous solutions with EDTA modified groundnut husk is particle-diffusion controlled (Kp is the rate coefficient for particle diffusion control corresponding to the particle size of the adsorbent). This seems to be due to increase in surface area and exposure of functional groups responsible for metal binding. Other studies (Addour et al., 1999; Leusch et al. 1995) demonstrated that the larger the particle density of a biosorbent, the higher the metal uptake.

Shukla and Pai (2005) reported that Pb (II) ions adsorbed on the hydroxyl groups of the cellulose component; hydroxyl groups of the material form strong covalent bonds with dyes and create sites for metal chelation and adsorption with dyed material. Carboxylic and carboxylate groups have also been identified as the main metal-sequestering functional ionic groups in the cell wall (Horsfall and Spiff, 2004; Leusch et al. 1995; Romero-Gonzalez et al., 2001; Yun et al., 2001). Periasamy and Namasivayam (1994) reported that electrostatic forces as well as specific chemical interac-tion plays important role in metal adsorption.

Most cellulosic materials investigated have been found to be good adsorbents for heavy metals. Since they are readily available globally, research into the indigenous species of the different geographical locations should be encouraged. Most species need little or no processing for application to wastewater treatment.

Conclusion

This paper highlighted current studies on the use of various adsorbents obtained from biological materials for heavy metal removal from waters. Such materials include living and/ or dead biomass of algae, fungi, animal by-products and cellulosic materials. All of these have good potentials for heavy metals' removal from waters. Mechanisms of uptake include chemisorption and physio-sorption. The materials are readily available and relatively cheaper than synthetic resins. This field may therefore be utilized by developing countries to alleviate or at least, reduce the impacts of industrial water pollution on the aquatic environment.

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