Review Paper

Adsorption and Conventional Technologies for Environmental Remediation and Decontamination of Heavy Metals: An Overview

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ABSTRACT

The global growing of chemical and related industries using heavy metals containing materials as raw materials for production, generating hazardous wastes containing these toxic materials and discharging them into the environment have become an environmental issue and thing of concern. To minimize the health risks of these metals discharged into the environment, several technologies which include ion exchange, solidification/stabilization, electrokinetics, bio-remediation, chemical treatments, electrochemical treatments, coagulation/flocculation, Membrane-filtration and adsorption technologies have been developed by various scientists. These technologies have been applied successfully in industries for remediation of heavy metals contaminated wastes. This review paper presents an insight into these techniques that have been successfully applied for heavy metals remediation in both terrestrial and aquatic environments; their advantages and drawbacks.

Keywords: *adsorption; heavy metals; soil; water; remediation; pollution; environmental.*

1. INTRODUCTION

The toxicity of heavy metals e.g., chromium, arsenate, lead, mercury, nickel, cadmium etc., released into the environment as a result of anthropogenic activities has become a thing of global concern and environmental problems. These toxic high molecular weight and density metals are toxic not only to human but also aquatic organisms affecting several multiple organ systems when inhaled, ingested or absorbed by the body of living organisms. Several health risks associated with these metals include liver damage, heart diseases, kidney, reduced lung function and development of cancerous cells among other. [1-3] Several technologies have been developed and proposed for resolving the problems of heavy metals contamination in both terrestrial and aquatic environments. These technologies include chemical treatment, bioremediation, electrokinetics, ion exchang e, electrochemical treatments, membrane filtration, and adsorption and so on. [4-10]

Of these technologies, adsorption technologies are considered as the most effective and efficient for remediation of heavy metals in aqueous systems due to each of operation and handling, low cost and relative abundance of adsorption materials. There are various naturally occurring materials that have been reportedly used for adsorption of heavy metals. They include clay minerals, industrial wastes, biomass, biochar, activated carbon, bio-polymer etc., [10-13] Surface modification of these materials by could enhance the surface area, pore volume, and number of present active sites on the surface for improved heavy metals adsorption. [14]

2. Environmental Remediation And Decontamination Technologies For Heavy Metals

2.1. Environmental Remediation and Decontamination Technologies for heavy Metals in Contaminated Soils

2.1.1. Solidification/Stabilization (S/S) as remediation technique for heavy metals

Solidification/stabilization technology (S/S) is also known as encapsulation or immobilization technology. This technology is usually employed for modifycation of the physicochemical proper-ties of residue containing heavy metal contaminants to form a chemically bounded matrix. The technology has become the most commonly applied option for the treatment heavy metals in contaminated soils. Solidification process involves the formation of a solidified matrix that physically binds or encapsulates the contaminated material. Stabilization, also in other word known as fixation, involves the use of a chemical reaction to convert the waste to a less mobile form. [15-16]

The general approach for solidification/stabilization treatment processes of heavy metal contaminants involves injecting or mixing the treatment agents with the contaminated soils to form a matrix. [17] Cement, blast furnace slag and fly ash are inorganic binders commonly applied as treatment agents for S/S techno-logy while applied organic binder for this technology include bitumen among others. They encapsulate the wastes containing the contaminants by forming a crystalline, glassy or polymeric framework around the waste. The major mechanism by which high density metals are immobilized is by precipitation of hydroxides within the solid matrix. [17] The commonly used materials for immobilization of heavy metal contaminants are lime and Portland cement. In physical terms, the cement solidifies and cures within a short period of time therefore possessing a faster immobilization activity than the lime. [18] Chemically, both materials act to alkalinize the environment, thereby increasing the pH of the environment and decreasing the solubility of the contaminants. It is known that the solubility of a compound depends on a number of factors which include the pH of its environment. Hence, reduction in the mobility of heavy metal contaminants can be improved by alkalinizing the environment and by cementing the particles. [19] S/S technologies are not suitable for remediation of some forms of metal contamination, such as species that exist as anions e.g., Cr (VI) and arsenic or metals that don't have low solubility e.g., mercury. [20]

Vitrification which is another form of solidification/stabilization technology involves the passage of an electric current between electrodes. Retention of solids and incorporation of metals in the vitrified becomes the resultant effect of this process. Vitrification is a promising technology, growing and becoming of a commercial value showing very promising results in metals remediation. The technique has been employed to capture mercury and other volatile metals such as lead and arsenic. [21] Advantages of S/S technology include: simple design, cost-effective, large soil volume can be treated, and can be recommended for metals; while the disadvantages include: dependency on the soil characteristics and homogeneity of the mixture, it promotes only immobilization, it does not promote the treatment of the contaminant, it is short-lived and the process hindered by the depth of the contaminant.

2.1.2. Electrokinetic

Electrokinetic is a remediation technology is also known as electrokinetic processing of the soil, electromigration, electrokinetic decontamination or electrocorrection. This technique can be used to extract heavy metals and some types of organic residues, such as polycyclic aromatic hydrocarbons (PAHs) from soils, sludges and sediments contaminated by them. [22] Electrokinetic consists of the application of a direct current of low intensity between the electrodes immersed in the soil.

Electrokinetic electrode materials include graphite, stainless steel and platinum. [8]

For decades, the application of electrokinetic process for heavy metal decontamination has been considered promising. It has found application for the remediation of low permeability contaminated soils, where the electric field generated mobilized electrically charged, particles and ions in the soil by the processes of electromigration, electrophoresis and eletro-osmosis. [22] The remediation of heavy metals by this technique could be achieved in two ways *viz*: the direct extraction of metallic ions already in the metal form and the extraction of metallic ions using a posterior process of ion exchange resins. [23] Electrokinetic remediation can also be used to delay or prevent the migration and/or diffusion of the metal contaminants, directing them to specific sites and diverting them from the freatic sheets. [23] In a study conducted by, [8] they found that electro-osmotic flow under applied electric potential depends on a number of soils, contaminants and applied electric potential conditions. Electro-osmotic flow induced in the same direction of metal or complexed metal ions transport can enhance heavy metal removal. [8,24] investigated the feasibility of mobilizing precipitated heavy metals from soil by ionic migration using ethylenediaminetetraacetic acid (EDTA). In their research, they used EDTA solution to catholyte where it solubilizes the precipitated metals. The resulting complexes are then transported to the anode. The removal efficiencies were found to be very close to 100 % for Zn and Pb. [25] examined the efficiency of electromigration process in removing Pb (II), Cd (II) and Cr (III) from sandy soils. Their study showed the removal efficiencies more than 90 % for all three metals.

Merits of electrokinetics include: high efficiency of metal decontamination of the soil, *In situ* treatment is possible and it may be combined with other remediation technology e.g. bioremedition techniques. Demerits of this method are that treatment time depends on the distance between the electrodes, pH change in areas near the electrode could affect metal uptake. It is costly and cost depends on the contaminant concentration and soil. Lower efficiency in soils with low permeability is also a major disadvantage.

2.1.3. Chemical treatment

Chemical treatments techniques are designed and tailored towards decreasing the mobility or toxicity of metal contaminants in soil. Oxidation and reduction are the types of chemical reactions that are usually applied for this purpose. Chemical oxidation changes the oxidation state of the metal atom through the loss of electrons. Change in the oxidation state of metals upon chemical treatments can solubilize, detoxify or precipitate the metal contaminants. Commercial oxidizing agents that are available for chemical treatment, include potassium permanganate, hydrogen peroxide, hypochlorite and chlorine gas. [26][27] Reduction reactions change the oxidation state of metals by electron increase. Commercially available reduction reagents are alkali metals (Na, K), sulphur dioxide, sulphite salts, and ferrous sulphate among others. [7] Reduction of Cr (VI) to Cr (III) is a good example of chemical treatment necessary for remediation of wastes containing Cr (VI). Chromium in its Cr (III) form is readily precipitated by hydroxide over a wide range of pH values (Smith *et al*., 1995). Acidification can also be employed to enhance and improve Cr (VI) reduction. A metal like arsenic can be treated by chemical oxidation. The result of a study by [20] showed that arsenic stabilization may be achieved by precipitation and co-precipitation with metals like Fe (III).

Chelating agents (e.g., EDTA) that selectively bind with some metals may be used to extract metal contaminants from the soil matrix. [28,29] studied the several chemical washing procedures for Zn (II) contaminated soil to determine the metal extraction efficiency from using specific extractants namely: acid solution, chlorine, diethyl-enetriaminepentaacetic acid (DTPA), and EDTA. Their study showed 79% removal of Zn (II) with 0.001M EDTA, 85% with 0.003M EDTA at pH 2; 90% with 0.003 M DTPA, 79% with 0.001M DTPA, at pH of 2, and 85% with 0.003M DTPA at pH of 6. Their result also showed that about 99% of Zn (II) was in the form of Zn-EDTA complex at pH 6. Surfactants may be used in extraction of metals from soil. [21]

Chemical treatment techniques are becoming emerging and promising substrates for the treatment of matrices contaminated with highly toxic and recalcitrant substances, changing them to less toxic substances or more biodegradable intermediates. [30,31] The major advantages of this technique include its high mineralization capacity, it is cost-effective, it can be recommended for soils with high permeability and different reagents may be employed. The disadvantages include: mass transfer barrier of the adsorbed phase to the aqueous phase, risk of aquifer contamination by not recovered solvent, limitations for large-scale application (*ex-situ* treatment) and the use of strong acids causes destruction of the basic structure of the soil.

2.1.4. Biological treatment

Biological treatment technologies are can be employed for remediation of heavy metals contaminated soils.

Applications of Biological treatment technologies are not limited to inorganics but have been employed for the remediation organics. They are beginning to find application for metal decontamination. [32] Biological treatment exploits natural biological processes that allow certain plants and microorganisms to aid in the removal of metals by various mechanisms that include adsorption, oxidation and reduction processes, methylation and so on. [33] The major techniques involved in the bioremediation process are summarized:

2.1.4.1. Bioattenuation (natural process)

Bioattenuation involves the use of native microorganisms for passive remediation of the soil. This involves several natural processes of remediation, such as biological degradation, volatilization dispersion, dilution and adsorption of the contaminants. These processes are also applicable for heavy metals removal from contaminated soil. [34,35]

2.1.4.2. Biostimulation (or accelerated natural attenuation)

Biostimulation involves the addition of nutrients and/or decomposing agents in the contaminated soil with the aim of increasing the population of selected or endogenous microorganisms that can potentially degrade metal contaminants through oxidation and /or reduction processes. [36]

2.1.4.3. Biomagnification (or bioaugmentation)

Biomagnification process of remediation is usually achieved by increasing the population of native microbiota through inoculation of exogenous microorganisms (allochthonous). In this technique, the applied microbes are bacteria, philamentous fungi and yeasts. [35,37]

2.1.4.4. Land farming

This ex situ remediation technique is based on the placement of the contaminated soil in layers with maximum of 40 cm thickness and their processing with agricultural machines. [38]

2.1.4.5.Biopiles

Remediation technique involving the application of biophiles, is an *ex situ* bioremediation technique that involves the stacking of contaminated soils, stimulation of aerobic microbial activities, acceleration of the degradation of pollutants through aeration, addition of nutrients and correction of humidity. [16]

2.1.4.6. Composting

Composting, a biological remediation technique, involves compounding of organic structuring agents in the contaminated soil to potentially increase the porosity and airflow in them in order to foster the degradation of the contaminants. Energy is released during the degradation processes of the organic matter resulting in temperature increase, facilitating the action of different microbiological phases *viz*: mesophilic, thermophilic, cooling and maturation. [39]

2.1.4.7. Phytoremediation

Phytoremediation is a widely acceptable and applicable technique that involves the use of plants as heavy metals decontamination agent. There series of mechanisms of decontamination involved in phytoremediation of both organic and inorganic contaminants; they are: phytovolatilization, phytoextraction, phyto-degradation phytostabilization, vegetative strains, rhizofiltration and phytostimulation for the remediation. [40]

Merits of biological treatment as contaminants remediation technique include: Simple design and implementation, cost-effectiveness, large soil volumes can be treated, favourable public opinion, complete destruction of waste material, environment-friendly, reduced pollutant exposure, short treatment times, efficient and continuous process and equipments are not required. Also, disadvantages include: limitations for large scale application, risk of human pollutant exposure, limited to removal of biodegradable pollutants, slower than other methods. [40]

2.2. Remediation and Decontamination Technology for Heavy Metals in Contaminated Water

2.2.1. Physico-chemical methods

As discussed by, [41] Physico-chemical separation techniques are primarily applicable to particulate forms of metals, discrete particles or metal bearing particles. These physical separation techniques include: mechanical screening, flotation, gravity concentration, magnetic separation, electrostatic separation, hydrodynamic classification, and attrition scrubbing. [41] It has been noted that the efficiency of physical separation depends on various soil properties such as moisture content, magnetic properties, particle size distribution, heterogeneity of soil matrix, density between soil matrix, particulate shape, clay content, humic content, and metal contaminants and hydrophobic properties of soil surfaces. [20,42]

2.2.2. Chemical precipitation

Chemical precipitation is one of the most commonly and widely remediation techniques for heavy metal removal from industrial effluents containing these toxic metals. [43] The process of chemical precipitation is simple. It involves the precipitation of the target metal as hydroxide, carbonate, sulfide and phosphate. The mechanism of chemical precipitation processes is based on the gravimetric precipitation of the metal as insoluble precipitate by reacting dissolved metal in the solution with precipitant. In the precipitation process, very fine particles are co-precipitated along the chemical precipitants and coagulants. Precipitation and coagulation are accompanied by flocculation processes. Flocculation is required to increase the particle size of the metal contaminants for their easy removal as sludge. The metals precipitates form solids upon these treatments and are thus easily removed, wherefore, low metal concentrations can be discharged. Increased percent removal of the metal ion can be achieved by optimizing parameters such as pH, temperature, initial metal ion, concentration etc., [10]

However, a major drawback associated with chemical precipitation is that it requires a large amount of chemicals to reduce metals to an acceptable level for discharge and some of the chemicals used for precipitation are sometimes not eco-friendly. Other demerits of this method are huge sludge production and their disposal issues, poor settling, slow metal precipitation and aggregate formation of metal precipitates. Also chemical precipitation changes the aqueous pollution problem to a solid waste disposal problem. [44] Hydroxide treatment is the most commonly applied precipitation technique, due to its relative simplicity, low cost of precipitant (lime), and ease of operation in terms of pH control. [43]

2.2.3. Coagulation and flocculation

The coagulation-flocculation mechanism is based on zeta potential (ζ) measurement as the criteria to define the electrostatic interaction between pollutants and coagulant-flocculant agents according to. [45] Metals are removed by coagulation process through reduction in the net surface charge of the colloidal particles by electrostatic repulsion process. [46] The coagulation process is then followed by flocculation process which would increase the particle size through additional collisions and interaction with inorganic polymers formed by the organic polymers added. The larger particles can then be removed or separated by filtration, straining or floatation. Major draw backs of this process include production of sludge, application of chemicals and transfer of toxic compounds into solid phase. [47]

2.2.4. Electrochemical treatments (Electrolysis)

Electrolytic recovery is one of the technologies used to remove heavy metals from wastewater. This process involves the passage current through electrodes (two cathode plate and an insoluble anode) into an aqueous solution of the metal. The application of electrochemical process for treatment of wastewater containing heavy metals works by precipitating the heavy metals in a weak acidic or neutralized catholyte as hydroxides. Electrochemical treatments of wastewater could be achieved via series of mechanisms *viz*: electro-flotation, electrodeposition, electrooxidation and electrocoagulation.

[48] Electrode stabilization of colloids and precipitation by hydroxide formation to acceptable levels has become the most commonly applied heavy metal precipitation method, forming coagulants by electrolytic oxidation and destabilizing the contaminants to form flocs. [49] In electro-coagulation process, the coagulant is usually generated *in situ* by electrolytic oxidation of an appropriate anodic material; thus, charged ionic metal species are removed from wastewater in the process by allowing it to react with anion in the effluent. The major advantages of this process are its reduced sludge production, ease of operation and there is no requirement for chemical use. [49]

2.2.5. Ion exchange

Ion exchange has emerged the most widely applied technique for treatment of effluents containing metals. The ion exchanger can attract soluble ions from the liquid phase to the solid phase. Commonly used ion exchangers are the synthetic organic ion exchange resins which contains exchangeable ions (cations and anions). In this process, the ion exchange resins which are water-insoluble solid substances absorb positively charged ions from the metal-bearing solution release other ions with the same charges into the solution in an equivalent amount. For the treatment of heavy metals, the positively charged ions in cationic resins such as calcium, hydrogen, and sodium ions are exchanged with positively charged ions, such as nickel, copper and zinc ions, in the metal-bearing solutions. This technique is also applicable to removal of non-metals from their contaminated wastes. In a similar fashion, the negative ions in the resins such as hydroxyl and chloride ions can be exchanged with other negatively charged ions such as sulfate, chromate, cyanide, nitrate and dissolved organic carbon (DOC) in non-metals containing wastewater. [50] The whole process is cost-effective whereby ion exchange process normally involves low-cost materials. Its effectiveness for removal of heavy metals and non-metals of low concentrations from their respective contaminated solutions and ease of operation are a major advantage. A major drawback of this technique is that it can only be used for solutions with low concentration of metal ions and it is highly sensitive to the pH of the solution. [51]

2.2.6. Membrane Filtration

Membrane filtration has widely received considerable attention for the treatment of wastewater containing both metals and non-metals. The technique can be used to remove organic compounds, suspended solids, and inorganic contaminants such as heavy metals from their respective solutions. Ultra-filtration, Nano-filtration and reverse osmosis are prominent membrane filtration techniques that can be employed for heavy metals removal from solution containing them depending on the particle size that can be retained.

2.2.6.1. Ultrafiltration

Ultrafiltration (UF) utilizes permeable membrane to separate heavy metals, macro-molecules and suspended solids from inorganic solution on the basis of the pore size (5–20 nm) and molecular weight of the separating compounds. Depending on the membrane properties, ultrafiltration can achieve more than 90 percent of removal efficiency with a metal concentration ranging from 10 to 112 mg/L at pH ranging from 5 to 9.5 and at 2–5 bar of pressure. Major advantages of UF include: lower driving force and a smaller space requirement due to its high packing density. Polymer-supported ultrafiltration (PSU) technique makes use of water soluble polymeric ligands to bind metal ions and form macromolecular complexes by producing a free targeted metal ions effluent. [52] The PSU technology requires low energy for ultrafiltration and higher selectivity of separation of selective bonding agents in aqueous solution. PSU is also characterized by fast reaction kinetics. Complexation-ultrafiltration technique is similar to PSU which have also proven to be a promising alternative to technologies based on precipitation and ion exchange. [52] In the complexation-UF technique, cationic forms of heavy metals are first complexed by a macro-ligand in order to increase their molecular weight with a size larger than the pores of the selected membrane. The process has advantage that includes high separation selectivity due to the use of selective binders and low-energy requirements involved in the process is another advantage. [53] To concentrate selectively and to recover heavy metals in their solution, hybridization of ultrafiltration may be necessary. This hybridization could be achieved by the use of water-soluble metal-binding polymers in combination with UF. Water-soluble polymeric ligands are potentially powerful substances that bind directly with high molecular weight metals to remove them from their aqueous solutions and industrial wastewater through membrane processes.

2.2.6.2. Reverse osmosis

Reverse osmosis (RO) is another form of membrane filtration technique which separation process is based on the use of pressure to force a solution through a membrane that retains the solute on one side and allows the pure solvent to pass to the other side. The membranes used for RO is semi-permeable, that is, it only allows the passage of solvent and not of pollutants. The membranes used for reverse osmosis have a dense barrier layer in the polymer matrix where the separation occurs. Reverse osmosis can remove many types of molecules and ions from solutions, including inorganics, bacteria, organics and suspended solids. RO is applicable for in industrial processes for treatment of wastewater. Reverse osmosis involves a diffusive mechanism, so that separation efficiency is dependent on water flux rate, solute concentration and pressure. [54][55]

2.2.6.3. Nanofiltraion

Nanofiltration (NF) is another membrane filtration technique similar to reverse osmosis. The process of NF is more complex and advance than RO; hence, it is an advanced reverse osmosis. The major difference between Nano-filtration and reverse osmosis lies in the pore size of the membrane. Nano-filtration system possesses bigger pores that allow better flow and passage of both solute and solvent than reverse osmosis. Thus, much lower pressure is usually required to drive both solute and solvent through the membrane.

Consequently, the energy required for Nano -filtration processes becomes much lower compared to that required to operate reverse osmosis. Flows are easier and faster in nanofiltration process, though the separation is less thorough than that of reverse osmosis. [56] Another benefit of nanofiltration is its ability to remove larger dissolved solids in contrast to the RO making the process more prudent.

Though the permeability of nanofiltration membrane maybe higher than RO membrane, it has been found that the performance of NF in desalination processes is better for some brackish water. [57] Another study by [58] revealed better separation efficiency (100%) using nanofiltration for the separation of salts present in water than (99%) for reverse osmosis. Heavy metals such as Zn(II),Cu(II) and Ni(II) have been effectively removed by the application of naofiltration technique. [59]

2.2.6.4. Electrodialysis

Electrodialysis (ED) is another membrane separation in which ionized species in the solution are passed through an ion exchange membrane (thin sheets of plastic materials with either anionic or cationic characteristics) by applied electric field. When a solution containing ionic species passes through the cell compartments, electromigration occur. The anions migrate to the anode while the cations migrate toward the cathode, crossing the ion exchange membranes. [6] A prominent demerit of this technology is membrane replacement and the corrosion process. The membranes that are used in electrodialysis process are of different ion exchange capacity hence, the use of membranes with higher ion exchange capacity would result in better cell performance. Effects of parameters such as flow rate, temperature and voltage at different concentrations using two types of commercial membranes using a laboratory ED cell, on lead removal were studied by [60] and their results showed cell performance was improved by increasing the voltage and temperature of the system while separation percentage decreased with an increasing flow rate. The technique thus offers great advantages for the treatment of highly concentrated wastewater ladened with heavy metals. [60]

2.3. Adsorption technologies for heavy metals remediation in wastewater

Adsorption has become one of the alternative treatment techniques for wastewater containing both organic and inorganic pollutants.

Adsorption phenomenon involves a mass transfer process of solutes (adsorbates) to solid surfaces (adsorbent) in a solution containing both the adsorbates and adsorbent. In the process, the adsorbates become physical and or chemical bound to the surface of the adsorbent. [61] Various low-cost adsorbents have been synthesized from clay materials, polymers, agricultural wastes, Industrial by-products and so on and applied for the removal of heavy metals from their aqueous solutions. Activated carbons and biochars have also been used for the removal of various inorganics including heavy metals. [4] Other adsorbents which have been used for removal heavy metals include photocatalyst beads, red mud, coal, biomass, fertilizer industrial waste, algae, fly ash, waste iron, iron slags, hydrous titanium oxide, activated sludge biomass, etc., has generated increasing excitement. [62,63,11-13] The adsorption materials can be mechanically, physically, and or chemically modified for improved adsorption of metals.

Several, researches for the removal of heavy metals from their contaminated medium have been tailored on the use of agricultural by-products as adsorbents through biosorption process. [64,11] Bioresources such as coconut shell, maize cob or husk, hazelnut shell, pecan shells, rice husk, jackfruit, rice straw etc., can be used as an adsorbent for heavy metal removal after chemical modification or conversion by heating into activated carbon or biochar [65][66] found that the maximum metal removal occurred by these biomass adsorbents are due to the fact that they contain cellulose, lignin, carbohydrate and silica.

Useful biopolymers for adsorption of heavy metals usually possess a number of different functional groups, such as hydroxyls and amines that can bind directly with the metals. The presence of these functional groups increases the adsorption capacity for metal ion uptake. These properties make them useful and applicable in industries for removal of metals from effluents as they are capable of lowering transition metal ion concentrations to subpart per billion concentrations.

Polysaccharide based-materials are also described as biopolymer adsorbents (derived from chitin, chitosan, and starch) useful for the removal of heavy metals from the wastewater. The sorption mechanisms of these materials are complicated and pH dependent. [67]

Clay, a fine-grained naturally occurring and abundant material, has been used as an effective adsorbent to remove heavy metal ions (in their part per million) present in aqueous solution for more than a decade now. Clay has a property that shows plasticity through a variable range of water content, which can harden when dried. [68] Clay can absorb heavy metals by various mechanisms *viz*: direct bonding, surface complexation, ion exchange, etc. [62] The efficiency of adsorption depends on various soil characteristics such as particle size distribution, particulate shape, clay content, hydrophobic properties of particle surface, moisture content, heterogeneity of soil matrix, density between soil matrix and metal contaminants, magnetic properties, and other adsorption conditions such as pH, temperature, concentration, contact time and so on. [62][69] Clay can be modified by a number of ways that include: chemical modification, Biogenic modification, thermal/physical modification and by mechano-chemical coupling. [70] Several researches have shown that both raw and modified clay can effectively and efficiently remove heavy metals. [14,62,71-75]

3.0. CONCLUSION

Ion exchange, solidification/ stabilization, electrokinetics, bio-remediation, chemical treatments, electrochemical treatments, coagulation/ flocculation, Membrane -filtration and adsorption are technologies that have been successfully applied for environmental remediation of heavy metals. Though these technologies are considered to be efficient and effective but have limitations and drawbacks in their respective application. Among these techniques, bioremediation have been considered to be the best technology for the remediation of heavy metals in contaminated soil while adsorption technology have become the most efficient and effective for removal of heavy metals from their contaminated aqueous solutions.

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