

Role of different parameters and mathematical models for metal ions adsorption from industrial waste water

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ABSTRACT

Manuscript discussed the role of different parameters for the metal ions removal from industrial waste water. The metal ions removal from waste water is essential to decrease the diseases and environmental hazards caused by heavy metal ions. The different parameters of adsorption including the effect of contact time, dose, pH, temperature, kinetics and Brunauer-Emmett-Teller analysis is discussed. This manuscript focuses on biosorption of metal ions, competitive adsorption of metal ions and ligand based adsorption of metal ions. This manuscript also focuses on the commercially available adsorbent used in the removal of metal ions efficiently including polymeric adsorbent and activated carbon.

Keywords: waste water; adsorbent; adsorption parameters; kinetics model; isotherm model; pollution; water treatment.

1. INTRODUCTION

Recently, researchers are attracted towards the polysaccharide derived adsorbents. The contemplate interest accredited to their adsorption performances, biocompatibility and biodegradability accompanied by chemical modification. They possess low cost, non-toxic, safe for the environment and used in the removal of heavy metal ions and dyes [1,2,3]. Adsorption is a most promising, inexpensive and effective approach because of its sustainability, low energy consumption, versatile operation and no sludge generate which helps in the heavy metal ions removal from aqueous solutions [3,4,5].

Elements having atomic weights in the range of 63.5-200.6 and a specific gravity greater than the 5.0 comes under the extent of heavy metals. The treatment of waste water released from the industries includes heavy metal ions such as chromium, cadmium, arsenic, nickel, mercury, lead, zinc, copper [6]. These heavy metal ions mostly found in the water streams from mining operations, tanneries, electroplating, electronics, textile mill products and petrochemical industries [7].

In recent years a large number of adsorbents are designed and used in the removal of heavy metal ions such as active carbon, polymer resins and biomass materials. Due to commercial availability, polymeric materials and activated carbon are most widely used for the adsorption process. Before few years low-cost adsorbents include, cow bone, wood bark, bentonite clay was used. Nowadays novel adsorbent including modified iron oxide, carbon nanotubes and graphene sheets have been developed [8].

Globally, heavy metal pollution causes serious problems related to the health of humans and also the ecosystem. Heavy

metal ions are increased in the environment due to the modernization and urbanization. Heavy metal ions are non-biodegradable contaminants that can enter the body through food, water, soil and air and causes disease and various disorders. Various methods are used for the metal ions removal from wastewater such as ion-exchange, chemical precipitation, adsorption, membrane filtration, coagulation-flocculation and electrochemical method. Adsorption method is the most effective method for the removal of metal ions. [9,10,11]. Figure 1 shows the schematic diagram for the removal of heavy metal ions from waste water by using adsorbent.

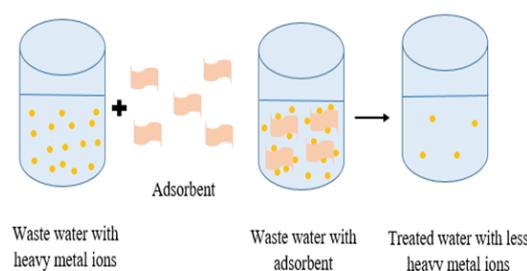


Figure 1. The schematic diagram for removal of heavy metal ions from waste water by using adsorbent.

2. DIFFERENT PARAMETERS EVALUATION FOR METAL IONS ADSORPTION FROM INDUSTRIAL WASTEWATER

2.1. Size.

In the study, it was evaluated that the size of the particles showed less effect on the total amount of copper fixation but the smallest size allowed rapid removal kinetics [12].

During the study, it was evaluated that wheat bran was used for the lead ions removal from wastewater. The removal of lead ions increased with a decrease in particle size due to the availability of the larger surface area [13].

2.2. Effect of contact time.

In the study it was observed that the metal ions adsorption by ion exchange in batch conical air spouted bed affects the contact time. The % removal efficiency increases when contact time increases until a plateau was reached at which the % removal efficiency hardly changes with time. The initial sudden increase in % removal particularly at high air velocities can be defined in the terms of the high driving force. While the driving force decreases with the increase of time as the metal ions being exchanged [14].

In the study, contact time effect of on removal of lead ions by NiOppt and NiOorg was studied. The equilibrium was attained after shaking for 120 min, which was considered as economic and adequate for wastewater treatment. According to this, the agitation time was fixed at 2 h for the rest of the batch experiments to make sure that equilibrium was attained [15].

During study it was observed that the adsorption rate was achieved fastly and attains equilibrium within 90 min. The 70% equilibrium adsorption was achieved in first 10 min. divulged a high affinity between the heavy metals and the adsorbents melamine based dendrimers amines grafted magnetic porous adsorbent [16].

In the study it was evaluated that effect of contact time on adsorption of metal ions by sulfonated cellulose was observed at 2 min to 20 min. At first 2 min the removal efficiency for iron, lead and copper was 97%, 84% and 40%. And the removal efficiencies were remaining unchanged when contact time is greater than 2 min. Extension of contact time has a little effect on adsorption performance and rapid adsorption of metal ions was feasible with sulfonated cellulose application [17].

The effect of contact time on the removal of lead and copper ions by using synthesized chitosan/titanium oxide nanofibrous adsorbents was observed. The sorption of ions reached the equilibrium time after 30 min of contact time for both nanofibrous adsorbents. Copper ions possess higher adsorption capacity because they have smaller hydrated ionic radius which caused copper ions to diffuse easily into the pores and adsorbed on the surface of both chitosan and titanium oxide nanofibrous adsorbent [18].

2.3. Effect of dose.

In the study the effect of adsorbent dose on the heavy metals adsorption was studied at contact time of 180 min for initial heavy metals concentration of 25-150 mg L⁻¹. The maximum adsorption of heavy metals was observed for the adsorbent dose of 4 g L⁻¹. After this dose no significant change was observed in percentage adsorption of heavy metals. It may be occurring due to the overlapping of active sites at a higher dosage. There was a decrease in the effective surface area which causes conglomeration of exchanger particles. So, 4 g L⁻¹ was evaluated as an optimum dose [19].

During study, zinc removal efficiency as function of adsorbents dosage was studied. On increasing the dose of the adsorbents more than 18 g/L for chitosan coated coconut shell carbon, 21 g/L for coated coconut shell carbon or 27 g/L for acid

treated coconut shell carbon yielded no increase in the zinc removal efficiency. The more efficient zinc removal occurs for chitosan coated coconut shell carbon was 90% at 18 g/L dose of the adsorbent, 21 g/L dose of coated coconut shell carbon exhibited 58%, whereas 25 g/L dose of acid treated coconut shell carbon. These observations suggest that adsorption of zinc ion in the wastewater was related to carbon surface area [20].

The effect of adsorbent dosage was studied on bael tree leaf powder to remove nickel ion from aqueous solution was investigated. This study describes the effect of adsorbent dosage varied from 5 to 30 g/L under 30°C temperature and with initial concentration at 10 mg/L. Result describes that the adsorption of nickel ion increases on the increase of dose of bael leaf powder from 5 to 20 g/L. Beyond this limit addition of adsorbent not cause a significant change in the adsorption due to the overlapping adsorption sites of adsorbent particles [21].

In the study it was observed that different amount of *Moringa aptera Gaertn* was used for the heavy metal ions removal. *Moringa aptera Gaertn* was used in different concentration varying from 0.25 to 1 g/100 mL of solution with 25-100 mg/L concentration of heavy metals with varying temperature from 20 to 70°C. From the result it was evaluated that the adsorption increased when the dose of sorbent increased. It was evaluated that maximum biosorption attained at dose of 1 g/100 mL was 90%, 70% and 95% for copper, nickel and chromium ions respectively [22].

During the study it was investigated that heavy metal ions removal from aqueous solution was occurs by using an adsorbent carbon aerogel. Adsorbent dose for heavy metal ions removal was increased over the range of 5-12 g/L, at pH 6. During the study the percentage removal of mercury ions shows 100% removal at concentrations (1-5 mg/L). It was observed that there was sharp increase in removal percentage with adsorbent dose for nickel and cadmium ions, lead and manganese ions but in case of copper and zinc ions there was a slight increase in percentage removal by increasing the dose [23].

2.4. Effect of pH.

Polysaccharides contain different functional group such as carboxyl, hydroxyl, phosphoryl, amino and sulfhydryl groups which acts as binding sites for protons and aqueous metal cations. pH can affect the both activity of functional group in polysaccharide and the ionization process of the metal ions [24].

In the study it was observed that removal of copper ions by crosslinked chitosan bead grafted with N-vinyl-2-pyrrolidone was studied at range of 2-6 pH. At acidic pH the removal of ions was very low because of the presence of the hydrogen ions which strongly compete with metal ions for adsorption sites. At pH 6, ions were formed precipitate as an insoluble copper hydroxide which causes a decrease in the percent of removal of ions [25].

During study it was observed that when the pH is less than 11, the wastewater containing heavy metals concentration decreases rapidly with an increase of pH. When the pH is greater than 11, heavy metal ions concentration is stable. When the pH is 11.5, the concentration of heavy metal ions reaches a minimum value. Eventually, the heavy metal ions concentration is no longer lowered [26].

In the study, it was demonstrated that maximum absorption takes place at pH 8 for water sample containing copper ion. At pH

8 metal ions are stable in copper ions because of the complexation of a metal ions with silver nanoparticles anchored with novel Schiff base. Increasing in the pH of solution, protonation of adsorbent surface gets decreased, site of adsorption being released, the adsorption quantity of metal ions increased. Increased pH indicates that the Schiff bases are available for metal ion binding and adsorption is getting increased [27].

Porous starch loaded with aluminium metal ions shows stable fluoride adsorption at pH 4-9. Below pH 3 or above pH 9 the adsorption capacity gets decreased. The adsorption of porous starch loaded with iron and lanthanum shows decreased adsorption when pH increased. The solution has pH of more than 9 adsorption process was decreased for porous starch loaded with zirconium. Low pH increases the protonation and generates a higher number of positively charged sites. The low pH of solution increases the electrostatic attraction force between the positively and negatively charged fluoride ions which can increase the capacity of adsorption.

At high pH the adsorption gets decreased due to the competition between fluoride and hydroxide ions for the adsorption sites and to increased repulsive forces between the negatively charged fluoride and the deprotonated surface [28].

2.5 Effect of temperature.

In the study, it was observed that when the distribution coefficient increased with an increase in temperature which shows that the endothermic nature of adsorption. The thermodynamic parameters like free energy change (ΔG°), enthalpy change (ΔH°) and entropy change (ΔS°) were estimated by using following equations.

The Gibb's free energy change of the process is related to the distribution coefficient (K_D) by the equation 1,2,3,

$$\Delta G^\circ = -RT \ln K_D \quad \text{equation 1}$$

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ \quad \text{equation 2}$$

$$\log K_D = \frac{\Delta S^\circ}{2.303 R} - \frac{\Delta H^\circ}{2.303 RT} \quad \text{equation 3}$$

Where K_D is the distribution coefficient ($\text{cm}^3 \text{g}^{-1}$), R is gas constant ($\text{kJ mol}^{-1} \text{K}^{-1}$).

From the above equation the value of ΔH° and ΔS° can be calculated from the slopes ($\Delta H^\circ/2.303R$) and intercepts ($\Delta S^\circ/2.303R$) of $\log K_D$ versus $1/T$ plots [29].

The stability of gum arabic modified magnetic nanoparticles was studied at temperature 340 K by agitating the nanoparticles for 60 min. in distilled water. The amount of gum arabic present on the surface of magnetic nanoparticles was analysed by thermogravimetric analysis. After heating the amount of gum arabic present on the surface of magnetic nanoparticles had no significant loss. The gum arabic modified magnetic nanoparticles were highly stable at 340 K temperature [30].

In the study, it was observed that the adsorption capacity of the metal decreased with the increasing temperature. The interaction of the metal ions and the active group of TMCS was lower at a higher temperature. The heat of adsorption determined at constant amounts of sorbate adsorbed is known as the isosteric heat of adsorption (ΔH_x) and was calculated by using Clausius-Clapeyron equation 4:

$$\Delta H_x = R \left[\frac{d(\ln C_e)}{d(1/T)} \right] \quad \text{equation 4}$$

Where, R is the molar gas constant (8.314J/mol K), C_e is the equilibrium concentration.

The result of adsorption data at different temperatures shows that the adsorption process was exothermic in nature [31].

During study, the effect of temperature on the adsorption was studied in the range of 10-50°C. Initial increase in the adsorption with the increase in the temperature upto 30°C, shows the endothermic nature of adsorption. The temperature increased to 40°C, a slight decrease in adsorption was found which indicates some desorption [32].

The effect of temperature on the adsorption of thorium and uranium on magnetic iron chitosan composite particles was studied in the range of 298.15-328.15 K, keeping all the other parameters constant at their optimum value, that is the sorbent mass (0.004 g), the target ion concentration (50 mg/L) and the contact time (120 min.). The results of the adsorption of both ions is favoured by an increase in temperature [33].

2.6. BET analysis.

The desorption isotherms on the basis of the Brrett-Joyner-Halenda method was used to derive the pore size distribution by the equation 5:

$$D = 4V_{\text{total}}/A_{\text{BET}} \quad \text{equation 5}$$

Where, A_{BET} ($\text{m}^2 \cdot \text{g}^{-1}$) is the specific surface area and V_{total} ($\text{cm}^3 \cdot \text{g}^{-1}$) is the total pore volume [34].

In the study it was investigated that the polysaccharide extract isolated from cactus pads (*Opuntia ficus indica*) used for the lead and cadmium metal ions removal. The BET analysis study showed that the surface area of the powdered extract was 2.373 m^2/g [35].

It was found in study that super adsorbent hydroxyapatite nanoparticles prepared by using natural polysaccharides. The specific surface area of these nanoparticles was analysed by using BET isotherm. It was found that carboxymethyl cellulose hydroxyapatite and chitosan hydroxyapatite have specific surface area of 70.709 m^2/g and 119.022 m^2/g [36].

2.7. Sorption kinetics.

For the sorption kinetics of pollutants different mathematical theories in modeling are available. The pseudo first order and pseudo second order kinetics are generally followed by the pollutants and described by the equations below,

2.7.1. Pseudo first order kinetic model. The pseudo first order kinetics is determined by equation 6,

$$\log(q_e - q_t) = \log q_e - k_1 t / 2.303 \quad \text{equation 6}$$

Where, q_e and q_t are the amounts of compound sorbed (mg g^{-1}) at equilibrium t time t (min) and k_1 is pseudo first order rate constant (min^{-1}).

2.7.2. Pseudo second order kinetic model. The pseudo second order kinetics is determined by equation 7,

$$t/q_t = 1/k_2 q_e^2 + t/q_e \quad \text{equation 7,}$$

where, q_e and q_t are the amounts of compounds sorbed (mg g^{-1}) at equilibrium and at time t (min), k_2 ($\text{g mg}^{-1} \text{min}^{-1}$) is the rate constant of pseudo second order [37].

In the study, it was investigated that amine functionalized mesoporous iron oxide nanoparticles used for the heavy metal ions removal. The adsorption of the heavy metal ions onto prepared nanoparticles reached equilibrium within 120 min at pH 7.0 and follows pseudo second order kinetic models with maximum adsorption capacities for lead, copper and cadmium ions from

369.0 to 523.6 mg/g. In the study, it was investigated that amine functionalized mesoporous iron oxide nanoparticles used for the removal of heavy metal ions. [38].

It was evaluated during study that acrylamide grafted copolymers of *Azadirachita indica* (neem) gum used in the synthesis of hydrogel. Prepared hydrogel used as flocculating agent and ineffective removal of cationic dye methylene blue from aqueous solution. The formulated hydrogel followed the pseudo second order kinetics model for the adsorption of methylene blue from aqueous solution [39].

2.8. Isotherms models.

Sorption equilibrium was described by different models.

2.8.1. Langmuir model. It assumes a monolayer adsorption of solutes onto a surface comprised of a finite number of identical sites with homogenous adsorption energy. Langmuir model was expressed as equation 8,

$$q = q_{max} \frac{b \cdot C_e}{1 + b \cdot C_e} \text{equation 8}$$

Where, q is the metal uptake capacity (mg of metal/g dry weight of biosorbent), C_e is the metal ions concentration in the solution (mg/L) when equilibrium is reached, q_{max} is the uptake capacity when the surface is completely covered with metal ions (maximum uptake capacity), b is a constant that represents the affinity between the biosorbent and the metal ion [45].

In the study it was investigated that Langmuir isotherm for the lead ions removal by using activated carbon produced from coconut shell showed the 24.4 mg/g adsorption capacity, followed by mercury and copper ions with adsorption capacity of 17.24 mg/g. Langmuir isotherm model provides a better correlation coefficient for lead and mercury ions while for copper ions correlation coefficient was low [40].

It was investigated that extracellular polymeric substances immobilized on microspheres and used in heavy metals removal. The adsorption process followed the Langmuir model and the parameters derived from the Langmuir equations indicated chemisorption [41].

Abdelfattah *et al.* werestudied that peanut husk powder used for the removal of various metal ions such as lead, manganese, cadmium, nickel and cobalt ions from contaminated water. The adsorption isotherm follows Langmuir isotherm model [42].

2.8.2. Freundlich isotherm. It was an empirical expression that takes into account the heterogeneity of the surface and multilayer adsorption to binding sites located on the surface of the sorbent. The Freundlich model does not consider the biosorbent saturation. Freundlich model was expressed as equation 9,

$$q = K \cdot C_e^{\frac{1}{n}} \text{equation 9}$$

3. BIOSORPTION OF METAL IONS

Biosorption is a property of inactive, non-living microbial biomass to bind and remove heavy metals from a very dilute aqueous solution. Biomass acts as chemical substance, as an ion exchanger of biological origin. In the research area biosorption is an ideal substitute for decontamination of metal-containing wastewater. The biosorption has some advantages such as growth independent, costly nutrients are not required for the growth of cells in feed solutions. The process is not governed by the physiological constraint of living microbial cells. The loading of metal on biomass is very high which leads to very efficient metal

uptake. The wider range of operating conditions like pH, temperature and metal concentration is possible. Aseptic conditions are not required for this purpose. Metal can be easily desorbed and then recovered if the biomass is abundant, metal-loaded biomass can be incinerated, thereby eliminating further treatment. Meanwhile, there is some disadvantages are also including such as, problem of early saturation, biological process improvement is limited because cells are not metabolizing. There is no potential for biologically altering the metal valency state [48].

Where K is the equilibrium constant of biosorption and n is a constant indicative of biosorption intensity. It was determined in the study that the bioflocculant was prepared by using acetonitrile as sole nitrogen source. The adsorption was followed Freundlich isotherm and the adsorption capacity of adsorbent was up to 439.2 mg^{1-1/n} l^{1/n} g⁻¹ and 112.2 mg^{1-1/n} l^{1/n} g⁻¹ for lead and copper ion. The kinetic study result demonstrates that adsorption of heavy metals was chemisorption [43].

In the study Guiza *et al.* wereevaluated the synthesis of cellulosic waste orange peel used in biosorption of heavy metal from aqueous solution. The adsorption of heavy metal by using cellulosic waste orange peel was followed Freundlich adsorption isotherm model [44].

2.8.3. Redlich-Peterson isotherm. The Redlich-Peterson isotherm approximates to the Henry’s law at low concentrations and Freundlich isotherm at high concentrations. Redlich-Peterson Isotherm expressed as equation 10,

$$q_e = \frac{k_{RP} \cdot C_e}{1 + a_{RP} \cdot C_e^b} \text{equation 10}$$

Where, k_{RP}, a_{RP} and b are the Re-P parameters. The value of b is between 0 and 1.

2.8.4. Sips model. The three parameter sips model is the combination of Freundlich and Langmuir models. The low sorbate concentrations approach to the Freundlich isotherm and at high sorbate concentrations approaches Langmuir isotherm and expressed by equation 11,

$$q = K_s \frac{C_e^{\beta S}}{1 + a_s \cdot C_e^{\beta S}} \text{equation 11}$$

Where, K_s is the constant of Sips model isotherm (L/g), a_s is the Sips model constant (L/mg) and βS is the exponent of this model [45]. Ramos *et al.* synthesized a new carboxylated functionalized sugarcane bagasse through the esterification of sugarcane bagasse with trimellitic anhydride. The sugarcane bagasse used for the removal of cobalt, copper and nickel ions. Mono component experimental data was fitted to Sips and Langmuir models isotherm [46].

Bohli *et al.* were studied the adsorption behaviour of heavy metals onto microporous olive stones activated carbon. The adsorbent adsorbs the copper, nickel and cadmium ions. The Langmuir and Sips model fitted for the mono-solute adsorption isotherms [47].

In the biosorption biomaterials are used such as algae, bacteria, fungi and yeast. It is considered as a cost effective biotechnology for the treatment of high volume and low concentration complex contaminated water containing heavy metal in the order of 1 to 100 mg/L. Wang *et al.* were determine the biosorption of heavy metal by *Saccharomyces cerevisiae*. Lead and uranium ions were removed from the dilute solutions more effectively in comparison to other metals [49].

Chu *et al.* was investigated the biosorption of dyes and heavy metals from industrial waste water. In study biosorption refers to the ability of living or dead biomass to confiscate pollutants like heavy metals and dyes through passive binding. Microalgae biosorption capacity is due to their high surface to volume ratio and high binding affinity. The cell walls of the microalgae have functional sites implicated in biosorption such as amino, carboxyl, phosphate, sulphate, imidazole and sulphhydryl moieties [50].

4. LIGAND BASED ADSORPTION OF METAL IONS

Awual *et al.* have been found that organic ligand based composite material was synthesized for the removal of nickel ions from waste water. It was observed that the adsorption capacity of composite was 199.19 mg/g due to the large surface area of composite [53].

During study Awual *et al.* was investigated that ligand based conjugate materials was used for the treatment of copper ions from wastewater. The excellent selectivity of copper ions was observed due to a complex formation between organic ligand of conjugate materials and copper ions. The adsorption capacity of conjugated materials was excellent and easily reaches the adsorption equilibrium [54].

In the study Awual *et al.* were found that the ligand based composite material was used in the removal of selective lead ions from contaminated water. The composite was prepared by the building block immobilization of (3-(3-(methoxycarbonyl)benzylidene)hydrazinyl)benzoic acid onto the highly mesoporous silica. The maximum capacity of adsorption was found to be 214.15 mg/g. The composite material was exhibited high selectivity towards the lead ions [55].

5. COMPETITIVE ADSORPTION OF METAL IONS

Park *et al.* were studied the competitive adsorption of heavy metal ions onto sesame straw biochar in waste water solution. The maximum adsorption capacities (mg g⁻¹) of metals by sesame straw biochar were in order of lead ion (102) > cadmium ion (86) > chromium ion (65) > copper ion (55) > zinc ion (34) in the monometal adsorption isotherm and the multimetal adsorption isotherm were in order of lead ion (88) > copper ion (40) > chromium ion (21) > zinc ion (7) ≥ cadmium ion (5). It was observed that cadmium ion was easily exchanged and substituted by other metals [58].

During study Deng *et al.* were observed that biochar synthesized through modification with chitosan and pyromellitic dianhydride was used as an adsorbent for the heavy metal ions removal from single metal and mixed metal solutions (cadmium, copper and lead). The study shows that chitosan pyromellitic dianhydride modified biochar had more selective adsorption of

In the study Alothman *et al.* were evaluated that the low cost biosorbent fungi used for the removal of heavy metals from wastewater. The synthesized biosorbent was designated for the good uptake property of the materials for target heavy metals [51].

Bano *et al.* were studied the biosorption of heavy metals by obligate halophilic fungi. Obligate halophilic fungi consist of *Aspergillus flavus*, *Aspergillus gracilis*, *Aspergillus penicillioides*, *Aspergillus restrictus* and *Sterigmatomyces halophilus* were used in the biosorption of lead, zinc, cadmium, copper, manganese and ferrous. All tested fungi showed moderate to high adsorption of heavy metals. The *Aspergillus flavus* and *Sterigmatomyces halophilus* showed the best average adsorption of heavy metal ions with an average of 86 and 83%. Obligate halophilic fungi remove iron and zinc ions effectively from an aqueous medium with an average of 85 and 84% [52].

Shahat *et al.* were synthesized the solid ligand-anchored composite material fabricated by the immobilization of the 8-hydroquinolone ligand onto the mesoporous silica nanospheres used for the adsorption of vanadium ions in wastewater samples and optical detection. The composite materials were shows the significant color on addition of vanadium ions. The adsorption capacity of the new composite was found to be 492.61 mg g⁻¹. The composite materials also exhibit the property of selectivity and sensitivity for the capture of vanadium ions from waste water [56].

Igeberase *et al.* were studied the adsorption of lead, zinc, copper, nickel and cadmium by modified ligand from aqueous solution. An amino functionalized adsorbent was synthesized by grafting 4-aminobenzoic acid onto the backbone of cross-linked chitosan beads. It was reduced the crystallinity and expand the polymer network for easy accessibility of the inspected metal ions to binding site. The adsorption was depending on pH, contact time, adsorbent dosage, agitation speed, initial concentration and ionic strength. The binding of metals ions was mainly controlled by electrostatic attraction, chemisorption and ion exchange [57].

copper ions. Chemisorption mechanism was followed by the heavy metal ions adsorption [59].

Berber *et al.* were investigated the heavy metal ions competitive adsorption from aqueous solution onto oxidized activated carbon fibre. The single metal adsorption on oxidized activated carbon fibre showed the adsorption capacity for nickel ions was 1.12 times greater than that of zinc ions. During the competitive adsorption zinc ion showed an intense antagonism to the adsorption of nickel ion and nickel to zinc ion. The single adsorption isotherm revealed that the selectivity of lead ions towards oxidized activated carbon fiber was slightly higher than the nickel ions. In the competitive adsorption, the affinity of lead ions was far greater than the nickel ions [60].

Fan *et al.* were studied the comparative and competitive adsorption of lead ions and copper ions by using tetraethylenepentamine modified chitosan/ cobalt ferrite particles. A maximum sorption capacity for copper and lead ions was found

to be 168.067 and 228.311 mg g⁻¹ in single component solution. In bi-component solution of lead and copper ions in 1:1 ratio the sorption capacity was found to be 139.860 and 160.256 mg g⁻¹ [61].

In the study, it was observed that Saha *et al.* were synthesized sulphur functionalized ordered mesoporous carbon. It

6. COMMERCIAL ADSORBENT

Commercial activated carbons are wood, peat, coconut shells, coals. An industrial scale adopted commercial materials are zeolites, commercial activated alumina, silica gels, ion-exchange resins and sand. Commercial activated carbon is mainly used for adsorbing contaminants from drinking water sources and also used in the removal of pollutants from wastewater [63].

Natural clay minerals are smectites (montmorillonite, saponite), mica (illite), diatomite, kaolinite, serpentine, pyrophyllite (talc), vermiculite, sepiolite, bentonite, fuller's earth. These clays are good adsorbent and the adsorption capacity depends on negative charge on the surface which makes clay adsorb the positively charged species. Natural mineral including zeolite and goethite is evaluated for the adsorption of pharmaceuticals. Zeolite is used for the heavy metals and dyes removal [64].

Activated carbon are islow cost hydrophobic materials with surface areas up between 300 and 2000 m²/g. Maxsorb III is a commercially available activated carbon. Maxsorb III hashigh Brunauer-Emmett-Teller around 3000 m²/g. Commercially available ion-exchange resins were used in the removal of heavy metal ions from industrial lean methyldiethanolamine solvent. But due to the presence of both amine and hydroxyl functional groups in ion exchange resin, heavy metal cannot remove successfully from lean methyldiethanolamine solvent and results

7. CONCLUSIONS

The manuscript focuses on the role of different parameters on the metal ions adsorption. The factors affecting the adsorption of metal ions from wastewater are determined by size, pH, temperature, dose, contact time, kinetics and BET analysis. The manuscript focuses on the biosorption of metal ions, competitive adsorption of metal ions and competitive adsorption of metal ions. The commercially available adsorbent is also discussed in this manuscript. It was concluded from the literature survey that at low

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can enhance the surface area and introduced sulphur functionalities onto the parent surface of carbon. The distribution coefficient for non-competitive adsorption was in the range of 2448–4000 mL/g for mercury, 290–1990 mL/g for lead, 115 to 147 mL/g for nickle and 550–560 mL/g for cadmium [62].

in metal amine chelation. Recently, GASCO company is using commercially available adsorbent activated carbon to remove cationic and anionic contaminants [65].

The six kinds of commercially available activated carbon made by coconut shell, saw dust and coal as raw materials were used as adsorbent. Charcoal manufactured by Wako Pure Chemical Industries, Darco G60, Norit “SX-11” manufactured by CABOT, Charcoal, Coconut shell and granule manufactured by Nacalai Tesque were used as activated carbon and used in the metal ions removal [66].

Commercially available macroporous resins are XAD-2 (4, 1600) from Rohm and Haas Co. (USA), Diaion HP-20 from Mitsubishi Chemical Co. (Japan) and X-5 from Nankai Chemical Plant (China). Commercially available polyacrylic ester adsorbents are Amberlite XAD-7, XAD-7HP, XAD-8 from Rohm and Haas (US), Wofatit EP62 and Y59 from Chemie AG Bitterfeld (Germany) and NDA-7 from Jiangsu NJU Environ. Co. (China). Hyper cross linked resins commercially available are NDA-701 and NDA-150 from NJU Environ Co. (China) and Hypersol-Macronet MN-200 and MN-250 from Purolite (UK). All this commercially available adsorbent is used for the water treatment [67].

pH adsorption of metal ions was very slow. The adsorption process gets increased on increasing the temperature. The adsorption of metal ions gets increased in decreasing particle size. The contact time increases with percent removal efficiency of metal ions with time. The adsorption of metal ions attained at different dose was also determined. BET analysis used to evaluate the size of adsorbent material. Most of the adsorption model follows the Langmuir isotherm and Pseudo-second-order kinetics.

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