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INVESTIGATION INTO ION EXCHANGE AND ADSORPTION METHODS FOR REMOVING HEAVY METALS FROM AQUEOUS SOLUTIONS

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ABSTRACT

With the increase in industrial activities, and increased building construction and urban growth, the environmental pollution caused by heavy metals has increased. Heavy metals are used in many industries, and so effluents of these industries contain substantial amount of heavy metals. Heavy metals have characteristics such as non- biocompatibility, toxicity, non-biodegradability, and great atomic weight. These ions can be stored in the food chains and transferred to humans and other organisms and cause various illnesses and diseases. Given the hazards of these metals to humans and other organisms, it is essential to remove them from water and wastewater. There are several methods to recover and remove them and adsorption is the most commonly used method. In the present review study, adsorption and ion exchange methods for the removal of heavy metal ions have been investigated and the advantages and disadvantages of these processes have been discussed.

Key words: Heavy metals, Ion exchange, Adsorption, Aqueous solution

INTRODUCTION

Since last centuries, water pollution by heavy metal ions have existed as a matter affecting the environment. The major source of heavy metals production is associated with increasing growth of industries which produce physical and chemical contaminants and release them into rivers. Heavy metals are produced by various industries such as metals coating, battery industry, mining [1], printing, ceramics, glass [2], pulp and paper,

petrochemical, pigments [3], burnish steel, coal-mining industry [4], textile [5], plating [6], chemical fertilizers and plastics [7] industries. Increasing the concentration of heavy metals in water is harmful to health because these metals are non-biodegradable. These metals due to non-biodegradability, toxicity and tendency to accumulate in organisms and penetrate into the food chain of humans cause various diseases. For example, cadmium can damage the kidneys and lead to high blood pressure. Lead can cause hazards such as anemia, brain damage, kidney and liver failure and infertility. Nickel ions are non-biodegradable and toxic, nickel poisoning causes headaches, dizziness, nausea and vomiting, chest pain, chest tightness, cough and shortness of breath, rapid breathing and severe weakness of the [8-11]. Many technologies and various methods such as chemical sedimentation, filtration, chemical oxidation and reduction, electrochemical processing, reverse osmosis, ion exchange, evaporation and adsorption are used to remove and recover heavy metals from industrial wastewater in order to minimize water pollution [12]. Among these techniques, adsorption is an efficient and economical method. Based on the basic concepts, this method is a simple and flexible operation, and in many cases consists of the use of reductive adsorbents to remove organic or mineral pollutants with high efficiency. Metal ions can be adsorbed through electrostatic attraction between the metal cations and by attacking negatively charged surface of the adsorbent. The adsorption process in recent years has been considered because of biocompatibility, excellent performance and low cost [10-12-13].

2-**Various heavy metals removal methods**

Today, in the face of stringent regulations, heavy metals are considered as one of major and dangerous environmental pollutants and have become one of the most important environmental problems. So to protect people and the environment, these toxic metals must be removed from industrial effluent and wastewater. Several methods such as chemical precipitation, ion exchange, adsorption, membrane filtration and electrochemical technology are used to remove heavy metal ions. Ion exchange and adsorption techniques have been discussed in the present study and also the advantages and limitations of their application have been investigated [14].

2-1- **Removal of heavy metal ions by ion exchange process**

Ion exchange resins are synthetic or natural solid resins which have the special abilities to

exchange their own cations with metals in wastewater. Among the materials used in ion exchange processes, synthetic resins which are almost effective on removal of heavy metals from aqueous solutions are usually used [15]. The ion exchange resins can be divided into two broad categories: (1) cationic resins, 2. anionic resins. Each group consists of strongly and weakly resins, and strongly resins and weakly resins generally exchange ions in a wide range of pH and a small range of pH of the sites, respectively [17-16]. The most common strongly acid cation exchangers are the sulfonic acid groups (-So3H) and carboxylic acid groups (-CooH) are the weakly acid resins. Hydrogen ions in the sulfonic group or carboxylic group of resins can serve as exchangeable ions with metal cations. The ion exchange process, exchanging the metal ions with hydrogen ions in the resin, is described below:

nR -So3H +M

n+

(R-So3-) n Mn+ + nH+

nR – COOH+ M

n+

(R-COO-) n Mn+ +nH+

Metal ions in this process are adsorbed by ion exchange resins instead of being under influence of variables such as pH, temperature, initial metal concentration and exposure time [18]. Ions charges play an important role in the ion exchange process. Abu- Farha et al. tested the impact of anionic charges on the removal of Fe3+, Ce4+ and Pb2+ from aqueous systems by ion exchange Purolite C100 resins and cation exchange [19]. They stated that the metal ions adsorption sequence was as Ce4+> Fe3+> Pb2+. Similar results for Ni2+, Co3+ and Cr3+ on an Ammberlite IRAN-77 cation exchange resin were previously obtained by Kang et al. [20]. In addition to synthetic resins, natural zeolites and natural silicate minerals are widely used to remove heavy metals from aqueous solutions due to their low cost and high abundance. Many researchers have shown that zeolite have a good cation exchange capacity for heavy metal ions under different laboratory conditions [21-23]. Clinoptilolite is one of the natural zeolites which have been widely regarded due to its power of choice for heavy metals. Recently, some researchers have reported that the clinoptilolite surface will be filled with amorphous forms of iron oxide, which significantly improves clinoptilolite exchange capacity [24-25]. Used Fe-Clinoptilolite system showed that Cu, Mn and Zn ions have been removed from drinking water simultaneously. Metal

systems have large adsorption capacities and in many cases treated water was suitable for human consumption and agricultural use. Although there are many reports of zeolite but montmorillonites are ion exchange resins for removal of copper but they are limited compared to synthetic resins. Zeolites are used on a laboratory scale. Further work is required to use zeolites on an industrial scale [26].

2-2- **Advantages of ion exchange process**

Ion exchange process is widely used to remove heavy metals from wastewater. The following advantages of this process can be cited:

1- High removal efficiency

2- Rapid kinetics

3- High processing capacity [27]

4- The process is highly selective.

5- Cost reduction can be provided due to the competition of the large number of resin manufacturers.

6- Design and operational experience are available.

7- The unit can be operated manually or automatically.

8- The process can be successfully used in the wide range of water treatment processes.

9- Due to the available experiences of exploitation, the process can be selected and designed by performing water contaminants tests.

2-3- **Disadvantages of ion exchange process**

1- High costs of reduction phase currents disposal

2- Low longevity of resins in the face of high pollution

3- Very high costs of reduction phase

4- Pollution of the majority of resins in the presence of organic materials [28-29].

3- Adsorption process

3-1- **The history of adsorption process**

However, the adsorption process has more than 4000 years of history in Sanskrit texts, but advanced use of it has a little history compared to other water treatment processes. The first granule activated carbon adsorption units were constructed for water treatment at Germany in 1929 and Michigan in 1930. Activated carbon powders were used for the first time at New Jersey, America, in 1930 to remove the taste and odor from water. According to pollution problems and people concerns of entering toxic agents and various pollutants sources into drinking water, the process of adsorption from 1970 is taken into consideration as an effective method for the removal of water pollutants [30].

3-2- **Advantages of adsorption process**

The advantages of adsorption can be summarized as follows, which cause the adsorption process be widely considered today:

1- Being flexible in design and operation

2- The high effect of this process on the reduction of heavy metal ions [14]

3- Simplicity and ease of operation [15]

4- Low cost and no sludge production [32]

5- The availability for local use and use of decentralized water treatment systems [33]

6- The feasibility of use at the entry point of water into the consumption place and small communities [34]

7- The feasibility of use at pollution seepage point [35]

8- The capability of producing adsorbent particles of different sizes and with maximum surface to mass ratio [36]

9- Ease of use in an emergency intentional and unintentional contamination of water resources [37]

10- The ability of recycling adsorbed materials [38]

3-3- **Adsorption process and low cost adsorbents**

Adsorption of heavy metals from aqueous solutions is a relatively new and very promising method to remove heavy metals. One of the major advantages of this process is the removal of heavy metal ions and the use of low cost adsorbent. The adsorption process is suitable for treating heavy metal ions, particularly diluted wastewater. Adsorbents are derived from three sources [39]: (1) Non-living biomass such as krill, crab, shrimp, and squid and lignin skins. (2) Algal bio-mass. (3) Microbial biomass such as bacteria, fungi and yeast. Since the agricultural wastes have no costs, they are used to adsorb heavy metals [40]. Various low-cost and non-living plant wastes such as potato skin [41], bran [42], and eggshell [43], cereals skin [44], and coffee husk [45], gel pectin / sugar [46] and citrus pulp [47] have been widely studied as the adsorbents because of their potential for adsorption. Some researches are carried out on metal adsorption using biomasses that are briefly discussed below: for example; Ajjabi and Chouba (2009) examined adsorption of Cu2 + and Zn2 + metal ions by C.lium dried green marine algae. An alga is a renewable natural biomass and is abundant in coastal areas. Thus, it has attracted attention of many researchers as a new adsorbent to adsorb metal ions. The use of algae as adsorbent has several advantages, including availability, low cost, high adsorption capacity and acceptable quality. In their study, the maximum adsorption of Cu2+ and Zn2+

were 1.46 and 1.97 mmol/g, respectively [48]. R.Lasheen Mohammed et al. (2012) studied adsorption and desorption of Cd2+, Cu2+ and Pb2+ ions by modified orange peel. The use of modified orange peel, compared to orange peel, showed that it has the significant adsorption capacity for heavy metals. Heavy metals reacted quickly with orange peel and the balance time was determined as 30 min [49].

CONCLUSION

Dangerous heavy metals are one of the serious problems of today societies. Heavy metals are substances with high molecular weight and are resistant to biodegradation and can have devastating effects on microorganisms and human cells. These metals are released into the environment through the effluents of many industries, including chemical, petrochemical, textile, automotive, battery industry, and reduce environmental sustainability. So, recovery and removal of heavy metals from aqueous solutions is an important issue. There are various methods for removal and recovery of heavy metals from aqueous solutions such as chemical sedimentation, adsorption, filtration processes, reverse osmosis and ion exchange. Some of these methods are not used due to high cost and low efficiency. Adsorption method is one of the methods which is widely used for removal of heavy metal ions. In the present review study, adsorption and ion exchange methods have been investigated and the advantages and disadvantages of these processes in the recovery and removal of heavy metal ions have been discussed. Among studied methods, adsorption had better abilities and advantages compared to ion exchange in the removal of metal ions. Some of the advantages of this method can be mentioned as follows: being flexible in design and operation, high effectiveness of this process on the reduction of heavy metal ions, simplicity and ease of operation, low cost, lack of sludge production and the ability to recycle adsorbed materials.

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