Journal of Water Process Engineering 10 (2016) 39–47

Contents lists available at ScienceDirect

Journal of Water Process Engineering

journal homepage: www.elsevier.com/locate/jwpe

A review on potential usage of industrial waste materials for binding heavy metal ions from aqueous solutions

Md. Juned K. Ahmed, M. Ahmaruzzaman*

Department of Chemistry, National Institute of Technology Silchar, Silchar 788010, India

ARTICLE INFO

Article history:
Received 12 August 2015
Received in revised form 21 January 2016
Accepted 26 January 2016
Available online 8 February 2016

Keywords:
Adsorption
Industrial wastes
Heavy metals
Sludge
Fly ash
Lignin
Red mud

ABSTRACT

Presence of toxic and recalcitrant heavy metal ions in industrial effluents is a major environmental concern. These fatal metal ions are not only hazardous in exceeding concentrations but due to the property of biomagnification it is urgent to look for the plausible solutions. This review article is an attempt to gather the research findings attempted in yester years for the removal of such metals from aqueous solutions by using waste materials from industries, such as blast furnace sludge, slag and flue dust, fly ash, black liquor lignin, and red mud. Studies have been complied keeping various efficiency influencing parameters such as optimum dose, contact time, initial concentration of metal ions, and many more in consideration. This article also tries to summarize the various problems and shortcoming of the work carried so far and attempts to explore the feasible suggestions.

Contents

* Corresponding author.
E-mail addresses: md_a2002@rediffmail.com, md_a2002@yahoo.com (M. Ahmaruzzaman).

http://dx.doi.org/10.1016/j.jwpe.2016.01.014
2214-7144/

1. Introduction

Environmental pollution of water and its control is an emerging global issue that need to be addressed for healthy environment. In recent years, the rapid growth of industries such as fertilizer, metal plating, tanneries, mining, and textile industries [1,2] have increased the discharge of toxic heavy metals into water streams, particularly in developing countries. Dyes, paints, printing, photography, paper, and petroleum refining industries also contributes to the presence of heavy metals in effluents. Elements with atomic weights in the range 63.5–200.6 and specific gravity greater than 5.0 comes under the purview of heavy metals. Unlike organic contaminants, heavy metals are not biodegradable and tends to accumulate in living organisms. Many heavy metal ions are known to be toxic and carcinogenic; and causes various diseases and disorders in human, animals, and aquatic life. Hence, they need to be removed prior to their discharge in water streams. In the treatment of industrial wastewaters, the toxic heavy metals of utmost concern include chromium (Cr), cadmium (Cd), and lead (Pb), zinc (Zn), copper (Cu), and nickel (Ni), arsenic (As) mercury (Hg). Therefore, stringent regulations are adopted worldwide and several regulatory bodies have set the maximum limits for the discharge of toxic heavy metals into natural water bodies. However, in actual practice such norms are often violated and consequently the ecosystem gets affected. Table 1 displays the permissible limits of various toxic heavy metals and their corresponding health effects [3–5].

The effective treatment of wastewater contaminated with toxic heavy metal ions has grown into an important research area. Chemical precipitation followed by coagulation has been widely used for the elimination of heavy metals from wastewater. However, this practice generates large volumes of sludge comprising minor quantity of heavy metals. Membrane filtration can remove metal ions but its use is limited due to high cost [6]. Adsorption is one of the most effective wastewater treatment technique that industries practice for the sequestration of toxic metals from the effluents. Activated carbon is the most widely used adsorbent and it shows good metal ion adsorption capacities [7–11]. However, the high cost of preparation limits its use in wastewater treatment. Over the last few years, a large number of researchers have investigated the utilization of industrial wastes for the uptake of heavy metals from wastewater [12].

This review article focuses on a summary of information relating to the utilization of industrial waste materials as adsorbents for the sequestration of heavy metals from wastewater. The review also discusses some critical issues and shortcomings on the use of industrial wastes as low-cost adsorbents.

2. Treatment techniques for heavy metal–laden wastewater

There are numerous techniques available for the treatment of heavy metal contaminated wastewater, such as microbial system, electrochemical process, and chemical precipitation, coagulation, photocatalytic degradation, and ion-exchange, adsorption, membrane filtration, etc. These techniques can be broadly divided into three categories: biological, chemical, and physical. Currently, no single process is capable of effective treatment due to the complex nature of the effluents. In real-time usage, a combination of various techniques are generally used for the treatment purpose. The advantages and disadvantages of different techniques adopted for the treatment of heavy metal–laden wastewater are shown in Table 2 [13].

3. Utilization of industrial wastes for the elimination of heavy metals from wastewater

In recent times, the removal of heavy metals from wastewater is gaining widespread attention among researchers. Amid various available techniques, the adsorption process can be considered as a simple and effective process for the removal of heavy metals. Industrial wastes are one of the low-cost adsorbents utilized for the remediation of heavy metal contaminated wastewaters. Industrial waste materials are generated as by-products or left-over materials in industrial processes. They often requires minimal processing to enhance their adsorptive capacities. Due to their abundant local availability, inexpensive nature, and high performance they are a good alternative to commercial adsorbents. Industrial wastes such as blast furnace slag, sludge, fly ash, lignin, and red mud have been utilized for the removal of toxic heavy metals from wastewater.

4. Summary of adsorption of heavy metals on industrial wastes

Herein, the important aspects and overview of some of the industrial wastes for the sequestration of toxic metals from wastewater is presented. Table 3 illustrates the summary of heavy metal adsorption on industrial wastes.

4.1. Sludge, blast furnace slag, and flue dust

Sludge is a dried waste produced in electroplating and effluent treatment plants, which consists of insoluble metal hydroxides and salts. Blast furnace slag and flue dust are industrial by-products from steel plants. These industrial wastes have been widely used by researchers for the removal of heavy metals from aqueous media.

Bhatnagar et al. compared the potential of various industrial wastes such as carbon slurry, blast furnace slag, dust, and sludge for the removal of Pb(II) from aqueous solutions [14]. The adsorption of Pb(II) follows the order: blast furnace sludge > dust > slag > carbonaceous adsorbent. The adsorption of Pb(II) and Hg(II) on non-viable activated sludge biomass were studied in batch and fixed-bed system [15]. The sorption data well-fitted to pseudo-second order kinetics and Langmuir isotherm models. The highest adsorption equilibrium, optimum pH, and temperature for Pb(II) were 0.387 mmol g^{-1} (C_o = 1.206 mM), pH of 3.5, and 30 °C; while for Hg(II) were 0.097 mmol g^{-1} (C_o = 0.099 mM), pH of 5.8, and 20 °C, respectively. Continuous-flow column data well-fitted to Thomas kinetic model. The basic oxygen furnace waste generated in steel plant has been used as a low cost adsorbent for the removal of Pb(II) from aqueous solution [16]. The effect of pH, adsorbent dosage, and initial metal ion concentration, contact time, and temperature on adsorption process was studied in batch experiments. Results of the equilibrium experiments showed that the solution pH was the key factor affecting the adsorption characteristics. Optimum pH for the adsorption was found to be 5 with corresponding adsorbent dosage level of 5 g L^{-1}. The equilibrium was achieved within 1 h of contact time. Kinetics data were best described by pseudo-second order model. The maximum uptake was 92.5 mg g^{-1}.

The blast furnace sludge (BFS), by-product and waste material of steelmaking industry was utilized as an adsorbent for Ni(II) ions removal from aqueous solution [17]. The equilibrium data were found to follow the Freundlich isotherm slightly better than Langmuir isotherm. The thermodynamic parameters revealed spontaneous and favorable adsorption of Ni(II) on BFS. The observed adsorption capacity was 90.91 mg g^{-1}, which indicates a good potential of BFS for its use in aqueous sorption system. In another investigation with sewage sludge, adsorbents were produced by two different procedures via microwave irradiation: (1) by one single pyrolysis stage (SC); (2) by chemical activation with $ZnCl_2$ (SZ) [18]. Subsequently, they were used for adsorption of Cu(II) from aqueous solutions. The effects of various experimental parameters such as pH and temperature were inves-