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Research paper

Drinking water treatment sludge as an efficient adsorbent for heavy metals removal

S.A. Abo-El-Enein[a], Ahmed Shebl[a,*], S.A. Abo El-Dahab[b]

[a] Chemistry Department, Faculty of Science, Ain Shams University, Abbassia 11566, Cairo, Egypt
[b] Holding Company for Water and Wastewater, Egypt

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ABSTRACT

Green chemists paid much more attention towards the alternative ways to reutilize waste materials instead of its disposal in a non-ecofriendly manner. In this study, drinking-water treatment sludge (DWTS), which is a by-product resulted from drinking water treatment plants, was successfully applied as an adsorbent for Pb(II), Cd(II) and Ni(II) removal from wastewater. The physicochemical characteristics of DWTS were investigated using X-ray diffraction (XRD), X-ray fluorescence (XRF), scanning electron microscopy (SEM) and N_2 adsorption-desorption isotherms.

The XRD analysis revealed that the DWTS under study consists of quartz and illite phases which had been reported for their adsorption efficiency. Firing of DWTS at 500 °C causes the appearance of albite phase in addition to previous ones which enhances the adsorption capacity of these materials. The influence of different parameters such as firing temperature of DWTS, contact time, pH, DWTS dose and initial metal ions concentration on the adsorption of heavy metal ions and, consequently, on their removal were investigated. DWTS exhibit an adsorption efficiency towards Pb(II) > Cd(II) > Ni(II). The extremely high efficiency of DWTS towards Pb(II) adsorption can nominate it as a specific low-cost adsorbent for Pb ions.

1. Introduction

Drinking-water treatment sludge (DWTS) is a by-product from the coagulation-flocculation process using aluminum or iron based salts to precipitate clay, colloidal particles, algae and humic substances from water resources. Due to its high production rate and its environmentally unfavored disposal to landfill, several researchers paid a considerable attention for using this waste material in different applications especially those of low cost. The chemical composition of DWTS varies depending on the source of water under treatment as well as the type of coagulant used. These applications include utilization of DWTS for ceramic products (Zamora et al., 2008; Kizinievic et al., 2013; Mymrin et al., 2017), cement and concrete production (Rodríguez et al., 2010; Sales et al., 2011; Hwang et al., 2017) as well as wastewater treatment as an adsorbent for the removal of phenolic compounds (Fragoso and Duarte, 2012), phosphates (Razali et al., 2007; Piaskowski, 2013), dyes from textile industry discharge (Chu, 1999) and heavy metals (Ippolito et al., 2011; Siswoyo et al., 2014).

Pollution of water resources by heavy metals such as lead, cadmium and nickel which are continuously discharged in huge amounts from different growing industrial activities has been recognized (Ribeiro et al., 2012; Yang and Cui, 2013; Keränen et al., 2015). These heavy metals are considered as hazardous materials where their toxicity to living organisms comes from their tendency to accumulate in living tissues since they are not biodegradable causing several health hazards like kidney problems, anemia, lung cancer and dyspnoea (Ahmaruzzaman, 2011; Visa et al., 2012). Therefore, a tremendous number of researches deals with the removal of such heavy metals especially via adsorption process (Bailey et al., 1999; Babel and Kurniawan, 2003; Ngah and Hanafiah, 2008; Tofighy and Mohammadi, 2015; Castaldi et al., 2015; Isaac et al., 2015; Dobrowolski et al., 2017; Azimi et al., 2017).

The aim of this study is to get a beneficial use of DWTS as a low cost adsorbent for the removal of lead, cadmium and nickel metal ions from wastewater.

2. Experimental

2.1. Starting materials

The material used in this investigation is DWTS waste produced during 4 months from El-Fustat drinking water treatment plant (Egypt).

* Corresponding author.
E-mail address: a_ahmed@sci.asu.edu.eg (A. Shebl).

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Table 1
Chemical oxide composition of DWTS.

Oxide	Weight, %
SiO_2	36.51
Al_2O_3	22.21
Fe_2O_3	5.65
CaO	2.66
Na_2O	1.35
MgO	1.34
K_2O	0.49
Sulphate as SO_3	0.08
Loss on ignition (L.O.I)	28.1

Its chemical composition is given in Table 1.

2.2. Preparation and firing of DWTS

DWTS was dried at 110 °C for 48 h, and then crushed. The crushed DWTS was fired at different temperatures of 100, 400, 500, 600 and 700 °C for a period of 2 h and then quenched in air.

2.3. Chemicals

The synthetic solutions used in this study were prepared from $Pb(NO_3)_2$ 99% produced by LOBA Chemie, $Cd(NO_3)_2{\cdot}4H_2O$ 99% produced by LOBA Chemie and $Ni(NO_3)_2{\cdot}6H_2O$ 98% produced by Oxford laboratory reagent. Solutions of 0.1 M nitric acid and ammonium hydroxide were used to adjust pH.

2.4. Batch adsorption experiments

Batch adsorption experiments including the effects of firing temperature, contact time, adsorbent dosage, initial metals concentration and initial solution pH were studied. Batch experiments were carried out at room temperature by addition of known weight of burnt DWTS into a number of 100 mL glass stoppered conical flasks on a rotary shaker at 200 rpm containing individual 50 mL of nitrate solutions of Pb(II), Cd(II) or Ni(II) (100 mg/L) in distilled water.

The effect of firing temperature was conducted to DWTS by shaking 0.5 g of DWTS, after burning at different temperatures (100, 400, 500, 600 and 700 °C), with 50 mL of the individual nitrate solutions of Pb (II), Cd(II) or Ni(II) (100 mg/L) in distilled water for 24 h. The effect of contact time was conducted by shaking 0.5 g of burnt DWTS at optimum firing temperature and individual nitrate solutions of Pb, Cd or Ni (100 mg/L) in distilled water for different time intervals of 2, 4, 6, 8, 12 and 24 h. The effect of initial pH was performed by shaking 0.5 g of burnt DWTS at optimum conditions of firing temperature and contact time and individual nitrate solutions of Pb, Cd or Ni (100 mg/L) at different initial pH values of 3, 4, 5, 6, 6.5, 7, 7.5, 8 in addition to original pH value of metal nitrate solution.

The effect of adsorbent dosage was conducted by adding desired amounts of burnt DWTS (0.5, 1, 1.5 and 2 g) at the optimum conditions with 50 mL of the individual nitrate solutions of Pb(II), Cd(II) or Ni(II) (100 mg/L) in distilled water. The effect of initial metals concentration was conducted by adding 2 g of burnt DWTS to 50 mL of the individual nitrate solutions of Pb(II), Cd(II) or Ni(II) having different concentrations of 100, 200, 300, 450 and 650 mg/L in distilled water. Effect of competitive adsorption at the optimum conditions was also carried out by mixing groups of Pb(II)-Cd(II), Pb(II)-Ni(II) and Pb(II)-Cd(II)-Ni(II) at different initial concentrations of 200 and 450 ppm.

2.5. Methods for physicochemical characterization

DWTS was characterized by X-ray fluorescence (XRF) technique using Pnanalytical Axios advanced XRF; as well as X-ray diffraction (XRD) analysis using a stabilized X-ray generator fitted with a copper target X-ray tube, (Geiger Muller tube). The settings used were tube run at 30 kV, 15 mA divergence, receiving and scatter solids, 1, 1, cm and 1 respectively and chart speed 100 C.P.S.

Adsorption–desorption isotherm of purified N_2 at 77K was carried out using Nova 2000, Quanta Chrome (commercial BET unit). The external morphology of DWTS was observed using scanning electron microscope (SEM) FEI Quanta 250 FEG. The heavy metals analysis was examined using Inductive Coupled Plasma (ICP) instrument Perkin Elmer Model: ICP – OES Optima 7300 DV; in which an ICP source consists of a flowing stream of argon gas ionized by an applied radio frequency field typically oscillating at 40 MHz; this generates about 6000 to 8000 K which called plasma. The high temperature of the plasma excites atomic emission efficiently. Ionization of a high percentage of atoms produces ionic emission spectra.

3. Results and discussion

3.1. Physicochemical characteristics of DWTS

3.1.1. Chemical composition

The results of chemical analysis of DWTS are given in Table 1 in terms of oxide composition. It is obvious that DWTS composed mainly of silica and alumina as a result of precipitated clay as well as coagulant used in the treatment.

3.1.2. X-ray diffraction analysis

The mineral composition of DWTS, fired at different temperatures, was identified by means of XRD analysis as shown in Fig. 1. The results indicate the presence of quartz and illite phases in all samples while albite phase appears additionally at 500 °C. It had been recorded in previous researches the potential application of quartz- silicon oxide- (Tikhomolova et al., 2001; Reich et al., 2010; Al-Anber, 2010; Bellucci et al., 2015) and illite (Ozdes et al., 2011; Benedicto et al., 2014a, 2014b; Cui et al., 2015) in heavy metal removal as adsorbents. Illite is a clay mineral of the layer type 2:1. It has the general formula of $K_yAl_4(Si_{8-y}, Al_y)O_{20}(OH)_4$, usually with $1 < y < 1.5$, and composed of two silica tetrahedral sheets that sandwich an alumina octahedral sheet (Alvarez-Puebla et al., 2005; Hongxia et al., 2016). The efficiency of illite as an adsorbent for heavy metal ions is ascribed to ion exchange reaction with its potassium ions that are trapped in its interlayer spaces; as well as inner-sphere complexes formation through $\equiv Si{-}O^-$ and $\equiv Al{-}O^-$ groups are located at the edges (McBride, 1994; Sheng et al., 1999; Celis et al., 2000; Gu and Evans, 2007).

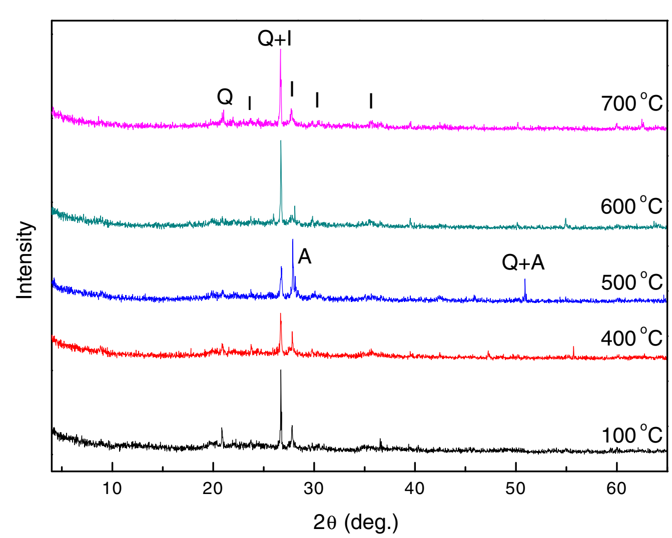

Fig. 1. XRD analysis of the DWTS fired at different temperatures. (Q = quartz, I = illite and A = albite).