A brief study on zinc oxide based nanosorbents and adsorptive removal of heavy metal ions

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Abstract

The liquid waste streams releases from industrial sectors contain numerous inorganic and organic pollutants. These pollutants may be heavy metals and synthetic dyes. Metal oxide based nanomaterials have been used in the removal of such pollutants from waste water by using adsorption techniques. The adsorption based removal of heavy metals is found good alternative over other conventional methods. ZnO nanoparticle based adsorbents have been utilised in the removal different heavy metal ions from waste water. These adsorbents are generally prepared by the incorporation of organic or inorganic materials with ZnO nanoparticles. In this brief review, we will be discussed about different ZnO based nanomaterials which potentially utilised in treatment of waste water containing heavy metals.

Keywords: Heavy metals, Adsorption,ZnO nanoparticles,Waste water treatments.

Introduction

The human activities such industrialisations, agriculture, urbanisations and domestic activities release a large number of inorganic and organic pollutants. Heavy metals are one of them and common heavy metals included lead, cadmium, mercury, chromium, copper, iron, zinc etc. Such metals are not biodegradable, not metabolised and not decomposed [1]. These heavy metals are also important for living organisms but under the concerned limits but many of them are highly hazardous to living organisms even at very low concentrations.The methods such as chemical precipitation, reverse osmosis, ion exchange, solvent extraction, electrochemical and adsorption have been used in the removal of heavy metals from water or waste water [2].

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Among all conventional methods, adsorption process is cost effective, efficient and applicable in the large scale operations of waste water treatments [3,4]. Nanotechnology has offered applications of nano sized materials in the fields of physical, chemical, biological and environmental sciences [5]. Nanotechnology is mainly related to the synthesis, characterisations and exploration of materials in the nano range (1–100 nm)[6].Due to many specific physical and chemical properties, the nanomaterials such as zinc oxide (ZnO), carbon nanotubes (CNTs), magnesium oxide (MgO), ferric oxide (Fe_3O_4), graphene, manganese oxide (MnO_2) and titanium oxide (TiO_2) have played the major roles in the treatment of waste water containing different heavy metals [7,8].

ZnO nanoparticleand adsorption

The zinc oxide (ZnO) nanoparticles serve as nanosorbent due to its good adsorptive properties, non-toxicity, chemical, thermal and mechanical stability [9]. The use of zinc oxide nanoparticles and their composites may have some disadvantages such as colloidal stability, agglomeration and lack of separating and recovering properties [10-14]. The adsorption study of heavy metals on the surface of nanosorbents in the laboratory scale is usually carried out under the batch system. The batch system includes contact time, pH, concentrations, dosage and temperatures. The optimized conditions found from the batch experiments can be applicable in the large scale removal processes of heavy metal ions from contaminated water [15-18]. The suitability of metal adsorption for a particular isotherm model indicates type of adsorption and it is an important step to find out a suitable isotherm model for design purposes. Various isotherm models such as Langmuir, Freundlich, Temkin, RedlichPatterson (R-P), Dubbin-Radush (D-R), Sips, Toth and Khan Isotherm models have been used to correlate the experimental results of adsorption [19-29] (Table:1). The kinetics of adsorption of heavy metals on to nanosorbents is an essential part in the better applicability of optimized batch conditions, rate and the mechanism of sorption. The four identified kinetic models for such studies are pseudo first order kinetic model, pseudo second order kinetic model, elovich kinetic model and intra particle diffusion [15,16] (Table:2).

Table:1 Isotherm models

Type of isotherms	Mathematical equation	Parameters
Langmuir	$C_e/Q_e = 1/K_l\, x + C_e/K_l$	K_l, x
Freundlich	$Q_e = K_f.C_e^{1/n}$	K_f, 1/n
Temkin	$Q_e = y + z \ln C_e$	y, z
Redlich Patterson (R-P)	$Q_e= K_{rp}C_e/1+\alpha.\ C_e^{\beta}$	K_{rp}, α, β
Dubbin-Radush (D-R)	$Q_e = Q_d \exp\{RT \ln (1+ 1/C_e)^2 /-2E^2\}$	Q_d, E
Sips	$Q_e= Q_s\, b\, C_e^{1/n} / 1 + S\, C_e^{1/n1}$	Q_s, $1/n_1$, b
Toth	$Q_e= Q_tC_e / (K_t + C_e^{1/n})$	Q_t, $1/n_2$
Khan	$Q_e= (Q_kB_kc_e) / (1 + B\, C_e)^{Ak}$	Q_k, B_k, A_k

*Terms: C_e = Equilibrium concentration of metal ions (mg/L), Q_e= Amount of metal sorbate per gram of sorbent (mg/g),K_l = Adsorption capacity, x = Energy of adsorption, K_f = Adsorption capacity, 1/n = Adsorption intensity, y = Binding constant at equilibrium time, z = Heat of sorption, K_{rp} = Binding capacity (L/g), α = Redlich Patterson constant, β = Exponent lies between 0 and 1, Q_d,= Adsorption capacity, E = Energy of adsorption, Q_s = Adsorption capacity, n_1 = Sips exponent, b = Energy of adsorption, Q_t = Adsorption capacity, n_2 = Toth model exponent, Q_k= Adsorption capacity,B_k = Khan model constant and A_k= Khan model exponent.

Table:2 Kinetic models

Kinetic models	Mathematical equations	Parameters
Pseudo first order	$\ln (Q - Q') = (\ln Q) - (k * t)$	K
Pseudo second order	$\frac{t}{Q} = \frac{1}{k'} * Q + Q$	k'
Elovich	$Q = k_E t^{1/2 +} I_e$	I
Intra particle diffusion	$Q = m + n \ln t$	m, n

*Terms: Q and Q′= Adsorption capacity at equilibrium and at time t, k and k' = pseudo-first and second order rate constant in min^{-1} and g/mol/min, I = the intra particle diffusion and m and n=initial adsorption rate (mg/g/min) and desorption constant.

Current studies

Various ZnO nanoparticles based adsorbent have been utilised in the removal of heavy metal ions from waste water. Joshi and Singh [16] have synthesised zinc oxide based nanosorbent (ZOBN) by using the leaves extract of *Shorearobusta* (Sal). This adsorbent was efficiently used in the removal of Pb^{2+} and Cd^{2+} ions from waste water. The ZOBN was well characterised by using FTIR, UV-Visible, XRD, FESEM and EDX methods. The adsorption efficiencies of Pb^{2+} and Cd^{2+} ions have been found 52.5% and 35.5% at contact time 60 min, 92.9% and 89.9% at pH 6 and 45.1% and 39.9% at temperature 60^{O}C, respectively.Sani et al. [29] has reported the utilisation ZnO/talc nanocomposite in the removal of Pb^{2+} ions from waste water. The ZnO/talc nanocomposite has been characterised by using the analytical techniques. The data of adsorption have been best fitted to pseudo-second-order kinetic model, Freundlich and the Langmuir isotherm models. The maximum lead adsorption capacity of ZnO/talc nanocomposite was found as 48.3 mg g^{-1}.

Kumar et al. [30] considered the synthesis, characterisation and utilisation of ZnO-NiObased nanocomposite as an adsorbent for the removal of Pb^{2+} and Cd^{2+}ions from waste water. The adsorption capacity was calculated as1519.7 mg$g^{-1}$for this material. The adsorption process showed chemisorption which was demonstrated by the pseudosecond order kinetic model. Yuvaraja et al [31]reported ZnO nanorods for the removal of As (III) from waste water. The ZnOnanorods have been characterised by using by XRD, FT-IR spectroscopy, SEM, and TGA. The maximum As^{3+} ionsadsorption capacity of ZnOnanorodshas been found to be 52.63 mg/g at pH 7, adsorbent dose 0.4 g, contact time 105 min, and temperature 323 K. Sani et al [32]have incorporated ZnO nanoparticles into the layers of montmorilloniteand utilised in the removal of copper and lead ions from waste water. The experimental data were indicated that this incorporated material can be best utilised in the removal of copper and lead ions under large scale treatments of waste water.Alswata and coworkers[33]have utilised the ZnO/Zeolite nanocomposite in the removal of lead and arsenic ions from the waste water. The maximum adsorption efficiencies of lead and arsenic ions have been recorded as 93% and 89%, respectively, at pH4, 0.15 g and 30 min.

Conclusions

This paper investigated the adsorptive performances of ZnO based nanosorbents for heavy metal ions from waste water. The adsorption study was adequately given with applying batch parameters, isotherms and kinetics. The recent study was comprised of the work of some researchers based on the adsorption of heavy metal ions by using ZnO based nanomaterials.

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