Removal of Lead Metal Ion from Aqueous Solutions Using Zinc Oxide Nanoparticles and Zinc Oxide Bulk Material

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Introduction

Many toxic heavy metals have been discharged into the environment as industrial wastes, causing serious soil and water pollution. Toxic metal compounds coming to the earth's surface not only reach the earth's waters but can also contaminate underground water in trace amounts by leaking from the soil after rain. Therefore, drinking water obtained from springs which may also be contaminated by various toxic metals. Pb^{2+}, Cu^{2+}, Fe^{3+}, and Cr^{3+} are especially common metals that tend to accumulate in organisms, causing numerous diseases and disorders (Inglezakis *et al.*, 2002). Among these lead (Pb^{2+}) is a highly toxic heavy metal which adversely affects the red blood cells of the human nervous system and kidneys (Potgieter *et al.*, 2006). According to World Heath Organization, the maximum permissible limit of lead in drinking water is 0.05 mg/L (Kanawade and Gaikwad, 2011).

The adsorption of heavy metal ions onto various solid supports such as activated charcoals, ion exchange resins, zeolites and ion chelating agents immobilized on inorganic supports is the most common route among the different techniques applied to remove dissolved heavy metals from waste water and industrial effluents (Chen *et al.*, 2003). Many methods using today for decontamination of waste water are not suitable in developing countries due to the high costs associated with production. Therefore, the use of alternative low-cost materials as potential sorbents for the removal of heavy metals should be investigated.

Among inorganic nanoparticles, the zinc oxide (ZnO) nanoparticle has received great attention because of its unique catalytic, antibacterial, electrical, electronic and optical properties as well as its low cost and extensive applications (Kathirvelu *et al.*, 2009). Zinc oxide bulk material and zinc oxide nanoparticles are widely used in industry and daily life for various things including as absorbents for gases such as CO, CO_2, O_2, H_2, SO_2, CH_4 (Scarano *et al.*, 2004). Therefore, the main aim of this study was to investigate the possibility of using ZnO nanoparticles and ZnO bulk material for the removal of Pb^{2+} from aqueous solutions by adsorption.

Methodology

Synthesis of ZnO nanoparticles were carried out according to the published procedure of Becheri *et al.*, 2008 and ZnO bulk material were prepared using the same method but without the peptization process. To evaluate the effect of pH on removal of lead ions in water, pH 6-9 solutions of 10 mg/L $Pb(NO_3)_2$ were prepared adjusting the pH values using phosphate buffers. 50 mg of ZnO nanoparticles were dispersed in 10 mL of each pH solution. After shaking the suspension for 4 hours at room temperature (25 °C) using an electric shaker the particles were separated via centrifugation (6000 rpm, 15 minutes), and the lead metal ion concentration was determined by atomic absorption spectroscopy (Varian Atomic Absorption Spectrophotometer with air-acetylene flame).

To evaluate the ability of ZnO nanoparticles and ZnO bulk material to remove Pb^{2+} from water at pH 7.0, 50 mg of ZnO nanoparticles and bulk material were dispersed in 10 mL of 10 mg/L Pb^{2+} solution separately and the same procedure as mentioned above was carried out to determine the remaining metal ion concentration in the aqueous solution. Six replicates and controls (without adding ZnO) were carried out using the same procedure and the results were statistically analyzed with two sample T-test using Minitab 14 software.

The adsorption isotherm of divalent metal ion (Pb^{2+}) was further determined by equilibrating ZnO bulk material (50 mg) in 10 mL of appropriate metal ion solutions (concentration range 5-100 mg/L) for 4 hrs. The adsorption capacities Q (mg/g) were obtained as follows: $Q = [(C_0-C_f)V]/m$; where C_0 and C_f are the initial and final concentrations (mg/L) of metal ion in the aqueous solution, respectively, V is the volume of metal ion solution reported in L and m is the weight of the adsorbent in g (Bystrzejewski *et al.*, 2009). The experiment was carried out in triplicates and average results were used for data analysis.

The effect of contact time of ZnO bulk material on lead ion removal was determined by following a similar procedure with different shaking times (30 min, 1 hour, 2 hours, 4 hours, 6 hours and 8 hours). Reusability of the ZnO sorbents were studied using previous once utilized ZnO bulk material.

Results and discussion

Highest adsorption (99.3%) of lead ions using ZnO nanoparticles was showed at pH 7 and adsorption at pH 6 was also more than 60 %. The initial lead concentration of 10 mg/L was reduced to 0.025 and 0.048 mg/L after applying ZnO nano particles and ZnO bulk material respectively. This reduction of lead ions in the solution was significant compared to control and initial concentration ($T_{nano} = 17.77$, $T_{bulk} = 17.73$; $P < 0.05$). However, the amount of lead ion adsorption by ZnO nanoparticles compared with ZnO bulk material showed no significant difference. Accordingly at pH 7.0 in room temperature (25 °C) the ZnO sorbents were very efficient and removed more than 99 % of lead ions in the solution. This amount is more than many conventional sorbents that have been used to remove lead ions in aqueous solutions (Payne and Abdel-Fattah, 2004).

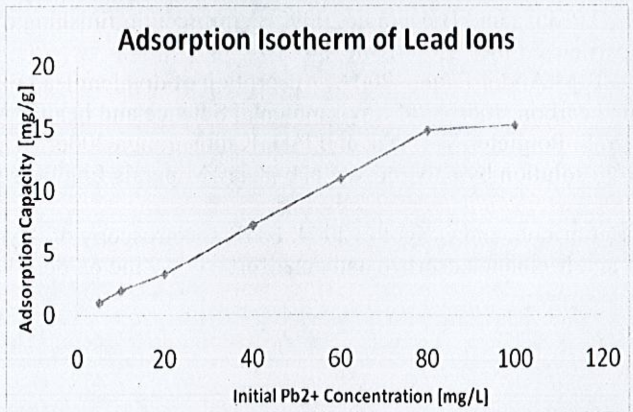

Figure 1: Lead ions adsorption isotherm of ZnO bulk material

The adsorption capacity is an important factor because it determines the amount of adsorbent, which is required for quantitative enrichment of the target analyte from a given solution. Figure 1 shows the adsorption isotherm of Pb^{2+} at their initial concentration range 5-100 mg/L. According to Figure 1 adsorption capacity (15 mg/g) has become constant after 80 mg/L concentration at pH 7 in room temperature. Adsorption capacity has become constant because, after 80 mg/L concentration, the sorbents have got saturated with lead ions, so that it is unable to absorb any more lead ions from the solution. The current adsorption capacity is very high compared to other heavy metal removing sorbents at similar concentrations (Bystrzejewski *et al.*, 2009).

According to this study there was no effect from contact time on percentage removal of lead ions in water and also there was no significant difference in adsorption between previously utilized and newly prepared ZnO particles.

In conclusion, ZnO nanoparticles and bulk material both are prospective materials for efficient removal of lead ion (Pb^{2+}) from aqueous solutions and the findings in this research are very important from application point of view for water and waste water treatments in order to remove toxic lead metal ions.

References

Bechari, A., M. Durr, and P. Lo Nostro 2008 Synthesis and characterization of Zinc Oxide nanoparticles, *Journal of Nanoparticles Research*, 10: 679-689.

Bystrzejewski, M., K. Pyrzynska, A. Huczko, and H. Lange 2009. Carbon-encapsulated magnetic nanoparticles as separable and mobile sorbents of heavy metal ions from aqueous solutions, Carbon. 47:1189-1206.

Chen, J.P., J.T. Yoon and S.Yiacoumi, 2003. Effects of chemical and physical properties of influent on copper sorption on to activated carbon fixed-bed columns, Carbon, 41(8):1635-44.

Inglezakis, V. J., M. D. Loizidou and H. P. Grigoropoulou 2002 Equilibrium and kinetics ion exchange studies of Pb^{2+}, Cr^{3+} and Cu^{2+}, on natural clinoptilolite, Water Research.36(11):2784-2792.

Kanawade, S. M. and R. W. Gaikwad 2011. Lead ion removal from industrial effluent by using biomaterials as an adsorbent, Journal of Chemical Engineering and Applications, 2(3):196-198.

Kathirvelu, S., L.D. Souza and B. Dhurai, 2009. UV protection finishing of textiles using ZnO nanoparticles. Fiber and Textile. 34:267-273.

Payne, K. B. and T. M.Abdel-Fattah, 2004. Adsorption of divalent lead ions by zeolites and activated carbon. Journal of Environmental Science and health. A39: 2275-2291.

Potgieter, J. H., S. S. Potgieter-Vermaak and P.D. Kalibantonga 2006. Heavy metals removal from solution by palygorskite clay, Clay Minerals Engineering, 19(5):463-470.

Scarano, D., S. Bertarione, and G.Spoto, 2004. FTIR spectroscopy of Hydrogen, Carbon monoxide, and Methane adsorbed and co adsorbed on Zinc oxide. Thin Solid Films, 400:50-55.