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Phosphate Removal From Waste Water Using Zinc Oxide

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Abstract: This study investigated the potential of zinc oxide (ZnO) for the removal of phosphate from wastewater. The effectiveness of ZnO was evaluated by varying pH, contact time, and adsorbent dosage. Results showed that ZnO achieved significant phosphate removal efficiency across all concentrations tested (50 mg/L, 10 mg/L, and 5 mg/L). The optimal conditions for ZnO were determined to be pH 5 and a 15-minute contact time with a adsorbent dosage 2 grams. Adsorption kinetics were best described by the second-order model, while isotherm data aligned with the Langmuir model, indicating monolayer adsorption. FTIR analysis confirmed phosphate adsorption onto the ZnO. The findings suggest that ZnO is a promising and sustainable material for phosphate removal from wastewater.

Keywords: *Zinc Oxide, Phosphate, Synthetic waste water, FTIR, Adsorption isotherm, ssoAdsorption kinetics.*

I. Introduction

Phosphates are essential nutrients for plant growth; however, excessive amounts in water bodies can cause severe environmental issues. The primary sources of phosphate contamination include agricultural runoff, where fertilizers containing phosphates enter water streams, industrial discharges from food processing and detergent industries, and untreated domestic wastewater. These contribute to eutrophication, leading to harmful algal blooms, depletion of dissolved oxygen, and destruction of aquatic life.

Existing phosphate removal methods include chemical precipitation using coagulants such as alum and ferric chloride, biological treatments like enhanced biological phosphorus removal (EBPR), and advanced membrane filtration. However, these methods often have high operational costs, require skilled labour, or generate secondary pollutants.

Hence, the need for an efficient, cost-effective, and environmentally friendly alternative is evident. Adsorption, using various materials, has gained attention due to its potential for sustainability, low cost, and high efficiency. This study explores the use of zinc oxide (ZnO), a metal oxide with known adsorptive properties, as a promising material for sustainable phosphate removal from wastewater due to its potential for effective adsorption.

1.1 OBJECTIVES OF THE STUDY

This study was aimed to achieve the following objectives:

- To develop a effective adsorbent using ZnO for phosphate removal.
- To evaluate the effectiveness of ZnO by varying pH, contact time, dosage, and influent concentration.
- To determine the adsorption capacity of ZnO using adsorption isotherms and adsorption kinetics.

1.2 LIMITATIONS OF CURRENT PHOSPHATE REMOVAL METHODS

Each of the common phosphate removal methods presents its own set of challenges. Chemical precipitation, while effective in removing phosphate through the use of coagulants like alum or ferric chloride, results in the production of substantial amounts of sludge, necessitating further expenditure for disposal and treatment. Enhanced biological phosphorus removal (EBPR), which harnesses the activity of specific bacteria, can suffer from inconsistencies due to operational sensitivities to factors such as temperature variations and pH levels, along with the demand for continuous monitoring. Membrane filtration techniques, including reverse osmosis and ultrafiltration, though efficient, are characterized by high costs, susceptibility to fouling, and the need for regular maintenance, rendering them less viable for large-scale or budget-conscious applications. Ion exchange resins offer selective phosphate removal but are also expensive and experience a decline in efficiency over time, necessitating frequent regeneration with strong chemical solutions. Finally, adsorption methods employing commercial adsorbents like activated carbon can incur significant costs and require periodic regeneration, thereby increasing overall operational expenses..

II. MATERIALS REQUIERD

2.1 CHEMICALS USED

a) Zinc Oxide
b) sodium hydroxide
c) Con. Sulphuric acid
d) Anhydrous potassium dihydrogen phosphate

2.2 INSTRUMENTS USED

a) UV-Visible spectrophotometer
b) Water analyser
c) Flocculator

III. METHODOLOGY

A phosphate solution with an initial concentration of 50 mg/L was prepared, and its pH was adjusted to 5, 6, 7, 8, 9, and 10 using 1N HCl and 1N NaOH. Adsorption studies were conducted by adding 1 g of sorbent to 200 ml of each pH-adjusted solution, followed by continuous stirring at 30 RPM using a flocculator. Samples were collected at time intervals of 15, 30, 45, 60, 75, and 90 minutes to determine the optimal pH and contact time for maximum phosphate removal. Subsequently, with the identified optimal pH and time, the effect of varying adsorbent dosage (1 to 6 g per 200 mL) on phosphate removal was investigated. This entire procedure was then repeated for influent phosphate concentrations of 5 mg/L and 10 mg/L.

IV.RESULTS

a) ZnO tested in 50 mg/L concentration:

Table 1: Effect of contact time and pH of ZnO in removing Phosphate

pH	5 minutes	10 minutes	15 minutes	30 minutes	45 minutes	60 minutes
5	36.64 %	43.97 %	58.62 %	49.34 %	45.92 %	40.06 %
6	25.40 %	35.66 %	47.39 %	33.54 %	24.43 %	22.96 %
7	19.05 %	26.38 %	35.17 %	31.75 %	21.98 %	17.10 %
8	15.63 %	29.80 %	41.52 %	30.78 %	26.87 %	20.52 %
9	8.79 %	22.96 %	38.10 %	32.24 %	26.38 %	14.17 %
10	3.42 %	24.43 %	32.24 %	23.94 %	19.05 %	11.72 %

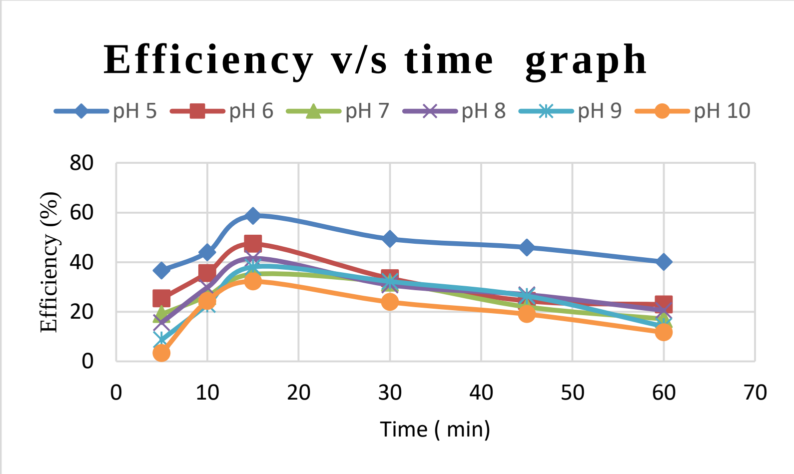

Fig 1: Effect of contact time and pH of ZnO in removing Phosphate

Initially, adsorption surpasses desorption. Maximum efficiency is achieved at equilibrium, where adsorption and desorption rates are balanced. Subsequently, desorption dominates. The experimental results show phosphate removal efficiency increases from 5 to 15 minutes, then declines. The equilibrium time was determined to be 15 minutes, and pH 5 was selected for subsequent analysis.

For finding the optimum dosage we put ZnO in samples that set in pH 5 and Contact time for 15 minutes.

Table 2: Effect of adsorbent dosage of ZnO in removing Phosphate.

Dosage	Efficiency
1g	58.62 %
2g	64.00 %
3g	51.78 %
4g	44.46 %
5g	33.22 %
6g	29.80 %

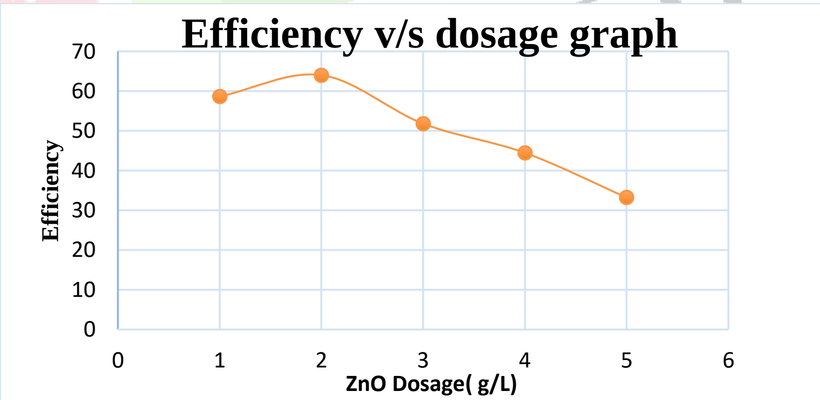

Fig 2: Effect of adsorbent dosage of ZnO in removing Phosphate. (50 mg/L conc.)

b) ZnO tested in 10 mg/L concentration:

Table 3: Effect of adsorbent dosage of ZnO in removing Phosphate (10 mL conc.)

Dosage	Efficiency (%)
1g	38.33
2g	49.92
3g	35.58
4g	29.82
5g	17.10
6g	15.25

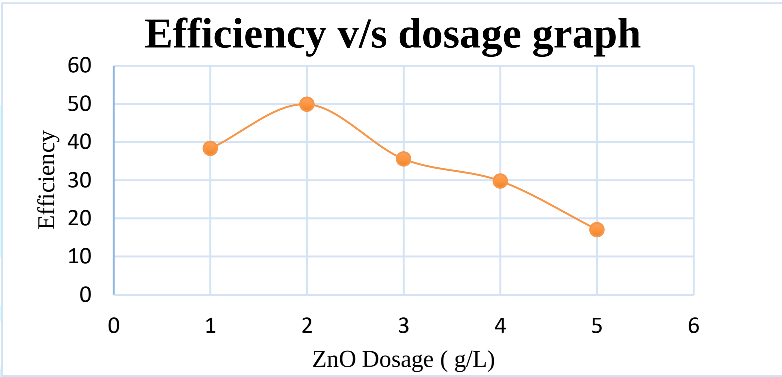

Fig 3: Effect of adsorbent dosage of ZnO in removing Phosphate

c) ZnO tested in 5 mg/L concentration:

Table 4: Effect of adsorbent dosage of ZnO in removing Phosphate (5 mg/L conc.)

Dosage	Efficiency (%)
1g	34.27
2g	48.45
3g	39.74
4g	25.17
5g	19.53
6g	15.63

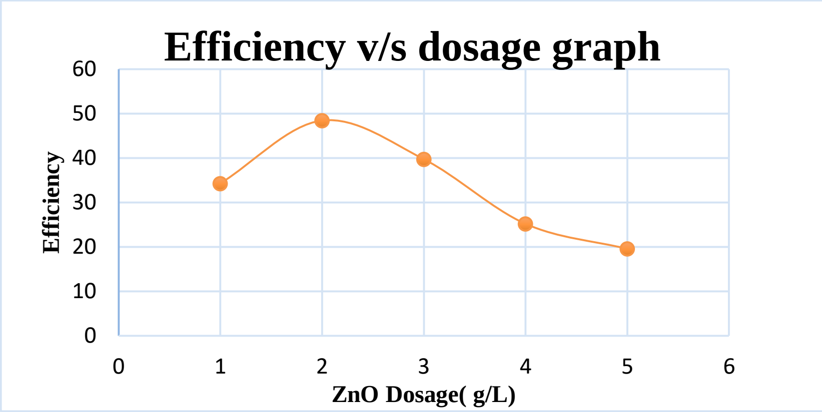

Fig 4: Effect of adsorbent dosage of ZnO in removing Phosphate (5 mg/L conc.)

Optimal dosage was determined for varying phosphate concentrations (50, 10, and 5 mg/L) using ZnO. Increasing sorbent quantity enhanced phosphate sorption, attributed to the greater availability of adsorption sites. However, exceeding 2 g/200 mL led to a decline in phosphate removal efficiency, possibly due to increased sorbent aggregation and subsequent desorption.

FINAL RESULT

Optimum pH value	: 5
Optimum time period	: 15 minutes
Optimum dosage for 50 mg/L concentration	: 2 grams
Maximum efficiency using ZnO for 50 mg/L conc.	: 64%
Optimum dosage for 10 mg/L concentration	: 2 grams
Maximum efficiency using ZnO for 10 mg/L conc.	: 49.92%
Optimum dosage for 10 mg/L concentration	: 2 grams
Maximum efficiency using ZnO for 10 mg/L conc.	: 48.45%

FTIR STUDY

Fourier Transform Infrared (FTIR) Spectroscopy is a powerful analytical technique used to identify chemical functional groups in a sample by measuring how it absorbs infrared (IR) light. It provides a molecular fingerprint of a substance, making it useful for material characterization, quality control, and chemical analysis.

FTIR works based on the principle that molecules absorb specific frequencies of IR light, causing their bonds to vibrate. These vibrations correspond to different functional groups, such as hydroxyl (-OH), carbonyl (C=O), carboxyl (-COOH), and amine (-NH2) etc. The absorption pattern is recorded as a spectrum, showing peaks at characteristic wavelengths (measured in cm^{-1}).Here, we have studied the FTIR of ZnO before and after treatment.

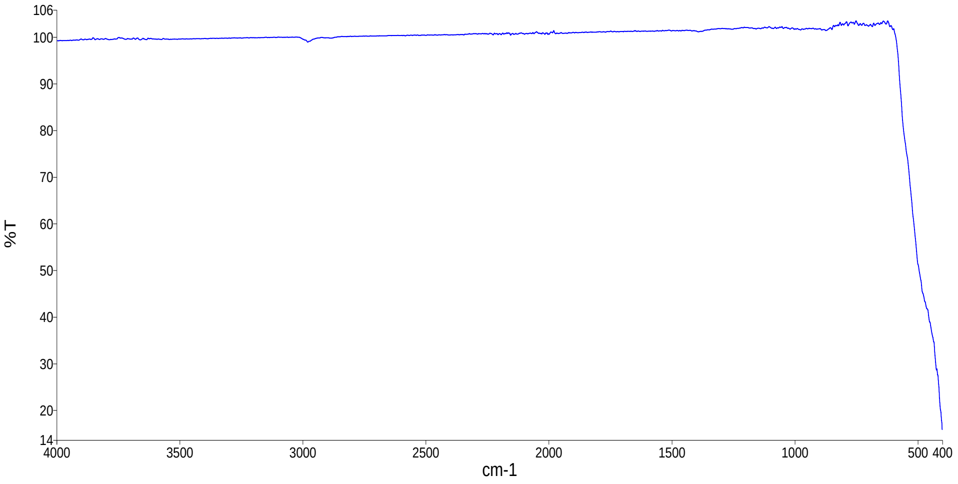

Fig 5: FTIR result of ZnO before treatment

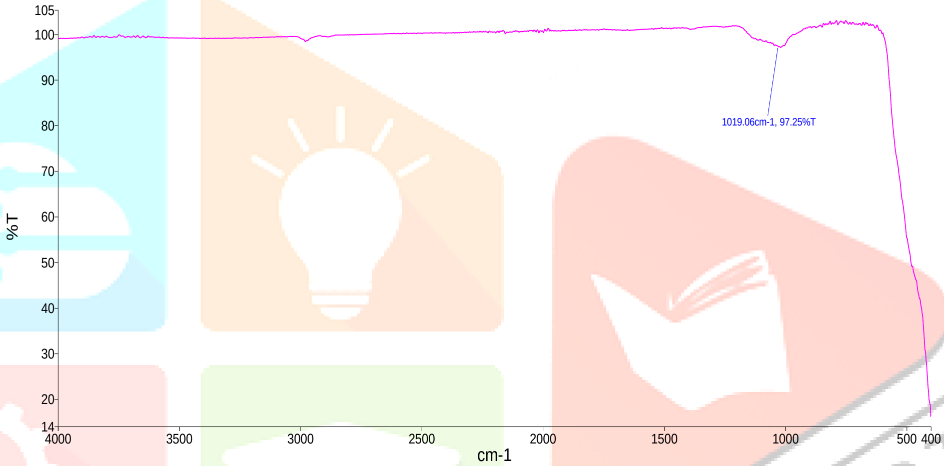

Fig 6: FTIR result of ZnO after treatment

The FTIR result shows that the presence of Zn-O (400 cm^{-1}) functional group in the before treatment result. And in after treatment result the Zn-O is attracted the phosphate group , that shows a new peak at 1019.06 cm^{-1}.So the adsorption of phosphate is shown clearly.

KINETICS AND ISOTHERM

a, Adsorption kinetics

The first-order kinetics model is used to describe adsorption processes where the rate of adsorption is proportional to the number of vacant sites on the adsorbent surface. The linear form of the first-order kinetic equation used in this study is:

$$log(q_e - q) = logq_e + \frac{K_d}{2.303} \times t$$

where:

q_e is the amount of adsorbate adsorbed at equilibrium (mg/g)

q_t is the amount of adsorbate adsorbed at time t (min)

k1 is the first-order rate constant (1/min)

t is the contact time (minutes)

A plot of log(qe−qt) versus t should yield a straight line with a slope of −k1/2.303 and an intercept of logqe if the adsorption follows first-order kinetics.

The second-order kinetics model assumes that the rate-limiting step of adsorption involves chemical adsorption. The linear form of the second-order kinetic equation is:

$$\frac{1}{q_t} = \left(\frac{1}{kq_e^2}\right)\frac{1}{t} + \frac{1}{q_e}$$

where:

t is the contact time (minutes)

q_t is the amount of adsorbate adsorbed at time t (mg/g)

q_e is the amount of adsorbate adsorbed at equilibrium (mg/g)

k 2 is the second-order rate constant (g/mg/min)

A plot of t/qt versus t should give a straight line with a slope of 1/qe and an intercept of 1/(k2qe 2) if the adsorption follows second-order kinetics. From the graph, the values of q_e and k2 can be calculated.

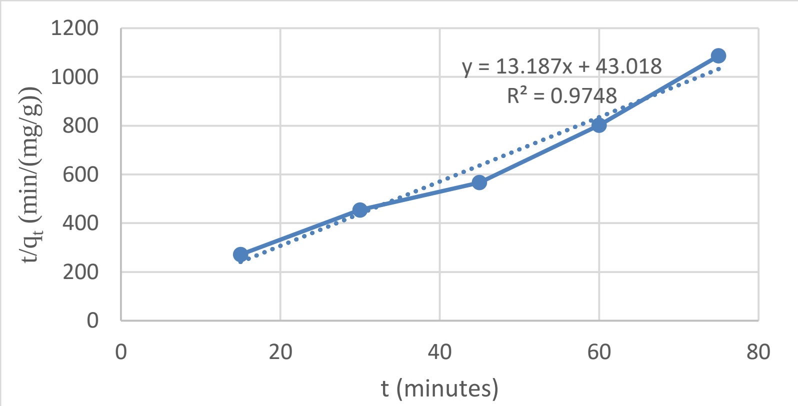

Fig 7: Second order kinetics for ZnO

The kinetics for the sorption of Phosphate on ZnO were evaluated using first-order and second-order models and the best model was assessed by the value of linear coefficient of determination (R^2). The study was conducted for a Phosphate concentration of 50 mg/L at pH 5. The graphical representation of the second-order kinetics model of ZnO is shown in figure 7.

Table 6: Adsorption kinetic model of ZnO for phosphate adsorption

Sorbent	**(q_e) (mg/g) (experimental)**	**second-order model**		
		k_2 (g/(mg·min))	q_e (mg/g)	R^2
ZnO	0.079	4.042	0.075	0.975

The second-order kinetics model showed higher R^2 value than first–order kinetic model. The maximum adsorption capacity figured from the second-order kinetics model displayed close proximity to the experimental. Hence the Phosphate sorption by ZnO followed second-order kinetics, which indicates the adsorption rate is dependent on adsorption capacity and not on the concentration of phosphate.

b, Adsorption isotherm

The adsorption behaviour of the sorbent was modelled by fitting the results of Phosphate removal obtained from experiments conducted for various influent Phosphate concentrations at Ph 5 and contact time 15 minutes into Langmuir and Freundlich isotherms. The best fit isotherm model is determined based on high R^2 values. Based on the data, the Phosphate adsorption behaviour ZnO was better defined by Langmuir isotherm (Fig: 8). The value of equilibrium parameter (R_L), obtained from Langmuir isotherm model lies between 0 and 1. This indicates the adsorption of Phosphate by ZnO from waste water was favourable under the given conditions.

Table 7: Isotherm parameters

Isotherm model	Parameters	ZnO
Langmuir	Q_o (mg/g)	0.0112
	b (L/mg)	2.1259
	R_L	0.383
	R^2	0.951

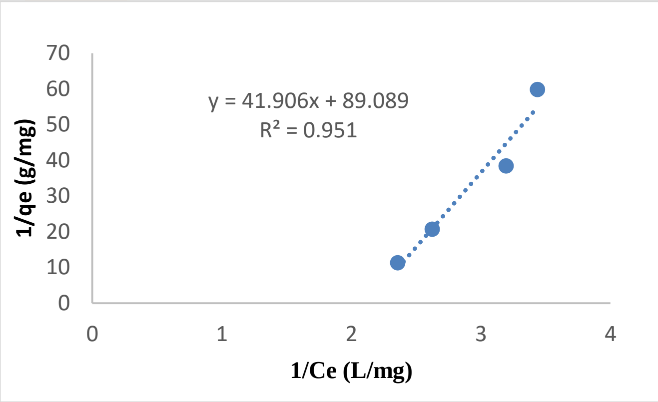

Fig 8: Langmuir isotherm (ZnO)

CONCLUSION

The present study successfully demonstrated the potential of zinc oxide (ZnO) for the sustainable removal of phosphate from wastewater. Experimental investigations revealed that ZnO exhibited effective phosphate adsorption capacity under optimized conditions, achieving significant removal efficiencies across the tested phosphate concentrations (50 mg/L, 10 mg/L, and 5 mg/L). The study determined the optimum conditions for phosphate removal using ZnO at pH 5 and a moderate contact time of 15 minutes, with a adsorbent dosage 2 grams. FTIR analysis confirmed the successful adsorption of phosphate ions onto the ZnO surface, indicating chemical interaction and bonding. Adsorption kinetics analysis revealed that the second-order kinetics model best described the adsorption process for ZnO, indicating that the adsorption rate is dependent on the adsorption capacity rather than the phosphate concentration. Furthermore, the Langmuir isotherm model provided the best fit for the adsorption isotherm data, suggesting monolayer adsorption of phosphate ions on the ZnO. The equilibrium parameter (RL) values between 0 and 1 confirmed that the adsorption process was favorable under the tested conditions. Overall, ZnO presents a promising, potentially cost-effective, and sustainable alternative for phosphate removal from wastewater.

REFERENCE

[1] Li, G., Gao, S., Zhang, G. & Zhang, X. (2014): Enhanced adsorption of phosphate from aqueous solution by nanostructured iron(III)–copper(II) binary oxides. *Chem. Eng. J.*, *235*, 124–131.
[2] Huang, W. Y., Zhu, R. H., He, F., Li, D., Zhu, Y. & Zhang, Y. M. (2013): Enhanced phosphate removal from aqueous solution by ferric-modified laterites: equilibrium, kinetics and thermodynamic studies. *Chem. Eng. J.*, *228*, 679–687.
[3] Lv, J. B., Liu, H., Liu, R., Zhao, X. L. & Qu, J. H. (2013): Adsorptive removal of phosphate by a nanostructured Fe–Al–Mn trimetal oxide adsorbent. *Powder Technol.*, *233*, 146–154.
[4] Ning, Z. L., Li, W. J., Sun, C. Y., Che, P. & Chang, Z. D. (2013): Synthesis and optical properties of zinc phosphate microspheres. *Trans. Nonferrous Met. Soc. China*, *23*, 718724.
[5] Pitakteeratham, N., Hafuka, A., Satoh, H. & Watanabe, Y. (2013): High efficiency removal of phosphate from water by zirconium sulfate surfactant micelle mesostructure immobilized on polymer matrix. *Water Res.*, *47*, 3583–3590.
[6] Salmani, M.H., Zarei, S., Ehrampoush, M.H., & Danaie, S. (2013): " Evaluations of pH and High Ionic Strength Solution Effect in Cadmium Removal by Zinc Oxide Nanoparticles", *J. Appl. Sci. Environ. Manage.*, *17*(4), 583-59.
[7] Zhang, H., Xu, M., Wang, H. J., Lei, D., Qu, D. & Zhai, Y. J. (2013): Adsorption of copper by aminopropyl functionalized mesoporous delta manganese dioxide from aqueous solution. *Colloid Surface A*, *435*, 78–84.
[8] Deng, H. & Yu, X. (2012): Adsorption of fluoride, arsenate and phosphate in aqueous solution by cerium impregnated f ibrous protein. *Chem. Eng. J.*, *184*, 205–212.
[9] Jiang, J. Q. & Ashekuzzaman, S. (2012): Development of novel inorganic adsorbent for water treatment. *Curr. Opin. Chem. Eng.*, *1*, 191–199.
[10] Li, G., Gao, S., Zhang, G. & Zhang, X. (2012): Enhanced adsorption of phosphate from aqueous solution by nanostructured iron(III)–copper(II) binary oxides. *Chem. Eng. J.*, *235*, 124–131.
[11] Liu, T., Wu, K. & Zeng, L. (2012): Removal of phosphorus by a composite metal oxide adsorbent derived from manganese ore tailings. *J. Hazard. Mater.*, *217–218*, 29–35.
[12] Lv, J. T., Zhang, S. Z., Luo, L., Han, W., Zhang, J., Yang, K. & Christie, P. (2012): Dissolution and microstructural transformation of ZnO nanoparticles under the influence of phosphate. *Environ. Sci. Technol.*, *46*, 7215–7221.
[12] Moezzi, A., McDonagh, A. M. & Cortie, M. B. (2012): Zinc oxide particles: synthesis, properties and applications. *Chem. Eng. J.*, *185*, 1–22.
[13] Zhang, L., Zhou, Q., Liu, J., Chang, N., Wan, L. & Chen, J. (2012): Phosphate adsorption on lanthanum hydroxide-doped activated carbon fiber. *Chem. Eng. J.*, *185–186*, 160–167.
[14] Bian, S. W., Mudunkotuwa, I. A., Rupasinghe, T. & Grassian, V. H. (2011): Aggregation and dissolution of 4 nm ZnO nanoparticles in aqueous environments: influence of pH, ionic strength, size, and adsorption of humic acid. *Langmuir*, *27*, 6059–6068.
[15] Liu, J., Wan, L., Zhang, L. & Zhou, Q. (2011): Effect of pH, ionic strength, and temperature on the phosphate adsorption onto lanthanum-doped activated carbon fiber. *J. Colloid Interf. Sci.*, *364*, 490–496.
[16] Vohla, C., Kõiv, M., Bavor, H. J., Chazarenc, F. & Mander, Ü. (2011): Filter materials for phosphorus removal from wastewater in treatment wetlands– a review. *Ecol. Eng.*, *37*, 70–89.
[17] Wang, L., Zheng, Y., Li, X., Dong, W., Tang, W., Chen, B., Li, C., Li, X., Zhang, T. & Xu, W. (2011): Nanostructured porous ZnO f ilm with enhanced photocatalytic activity. *Thin Solid Films*, *519*(16), 5673–5678.
[18] Zhou, J., Yang, S., Yu, J. & Shu, Z. (2011): Novel hollow microspheres of hierarchical zinc-aluminum layered double hydroxides and their enhanced adsorption capacity for phosphate in water. *J. Hazard. Mater.*, *192*, 1114–1121.
[19] Chouyyok, W., Wiacek, R. J., Pattamakomsan, K., Sangvanich, T., Grudzien, R. M., Fryxell, G. E. & Yantasee, W. (2010): Phosphate removal by anion binding on functionalized nanoporous sorbents. *Environ. Sci. Technol.*, *44*, 3073–3078.
[20] Foo, K. & Hameed, B. (2010): Insights into the modeling of adsorption isotherm systems. *Chem. Eng. J.*, *156*, 2–10.
[21] He, H. M., Kang, H. L., Ma, S. L., Bai, Y. X. & Yang, X. J. (2010): High adsorption selectivity of ZnAl layered double hydroxides and the calcined materials toward phosphate. *J. Colloid Interf. Sci.*, *343*, 225–231.

[22] Miao, A. J., Zhang, X. Y., Luo, Z. P., Chen, C. S., Chin, W. C., Santschi, P. H. & Quigg, A. (2010): Zinc oxide-engineered nanoparticles: dissolution and toxicity to marine phytoplankton. *Environ. Toxicol. Chem.*, *29*, 2814–2822.
[23] Cheng, X., Huang, X., Wang, X., Zhao, B., Chen, A. & Sun, D. (2009): Phosphate adsorption from sewage sludge filtrate using zinc-aluminum layered double hydroxides. *J. Hazard. Mater.*, *169*, 958–964.
[24] Haghseresht, F., Wang, S. & Do, D. (2009): A novel lanthanummodified bentonite, Phoslock, for phosphate removal from wastewaters. *Appl. Clay Sci.*, *46*, 369–375.
[25] Rentz, J. A., Turner, I. P. & Ullman, J. L. (2009): Removal of phosphorus from solution using biogenic iron oxides. *Water Res.*, *43*, 2029–2035.