PHOSPHATE REMOVAL FROM WASTEWATER USING SLAG AND ION EXCHANGE RESINS

By

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CERTIFICATE OF AUTHORSHIP/ ORIGINALITY

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Nomenclature

a = Langmuir constant

AC = activated carbon

Al^{3+} = Aluminum

b = Langmuir constant

BW = boron waste

C = the bulk phase concentration (mg/L)

$Ca(OH)_2$ = Calcium hydroxide

C_e = equilibrium concentration of adsorbate (mg/L)

C_o = initial concentration of adsorbate (mg/L)

C_o = inlet adsorbate concentration (mg/L)

C_s = the concentration on the external surface (mg/L)

C_t = concentration of adsorbate at time t (mg/L)

C_t = outlet adsorbate concentration at time t (mg /L)

C_{Ek} = the concentration of potassium ions in solution at equilibrium

Ca^{2+} = Calcium (II)

Cl^- = chloride

CO_3^{2-} = carbonate

Cu^{2+} = Copper (II)

D_m = molecular diffusion coefficient

D_s = the surface diffusion coefficient (m^2/s)

EXAFS = X-ray absorption fine structure

Fe^{3+} = iron (III)

F = the linear velocity calculated by dividing the filtration velocity by column section area

FeO = zero-valent iron

g/L = gram per litre

HAIX = hybrid anion ion exchange

H_3PO_4 = Phosphoric axit

$H_2PO_4^-$=dihydrogen phosphate ion

HCl = hydrochloric acid

HCO_3^- = bicarbonate

HFO = iron (iii) oxide

hr = hours

K = a constant called the "half value".

K^+ = Potassium

k_f = the external mass transfer coefficient (m/s)

K_F = Freundlich constants (mg/g)

K_L = Langmuir constant related to the energy of adsorption (L/mg)

k_{Th} = Thomas rate constant (mL/min.mg)

k_{YN} = rate velocity constant (1/min)

k_1 = equilibrium rate constant of pseudo-first-order sorption (1/min)

k_2 = equilibrium rate constant of pseudo-second-order (1/min)

k_{AB} = kinetic constant, (L/mg.min)

KNO_3 = Potassium nitrate

KH_2PO_4 = Monopotassium phosphate

KCl = Potassium chloride

LDHs = layered double hydroxides

M = mass of dry adsorbent (g)

MIEX = magnetic ion exchange resin

mg P/L = milligram phosphorus per litre

mg PO_4^{3-} / g = mg phosphate per gram

mg P/g = milligram phosphorus per gram

min = minutes

mL/min = millilitre per minute

m/h = meter per hour

Mg0 = zero-valent magnesium

μ = Solution viscosity

N = nitrogen

Na^+ = sodium

NaCl = sodium chloride

NaOH = sodium hydroxide

Na_2SO_4 = sodium sulphate

Na_2CO_3= sodium carbonate

$NaHCO_3$ = sodium bicarbonate

NH_3 = Ammonia

N_o = saturation adsorbate concentration (mg/L)

n = Freundlich constant

pH = measure of the acidity or basicity of an aqueous solution

Q = Flow rate (cm3/s)

q = surface concentration at any radial distance (r) (mg /g)

q_e = loading of potassium on the resin at equilibrium (mg/g),

q_e = amount of adsorbate adsorbed per unit mass of adsorbent (mg/g)

q_{max} = maximum amount of adsorbate adsorbed per unit mass of adsorbent (mg/g)

q_o= equilibrium adsorbate uptake per g of adsorbent (mg/g)

rpm = Revolutions per minute

SEM = Scanning electron microscopy

SFS = Steel Furnace Slag

M-SFS = Modified Steel Furnace Slag

SO_4^{2-} = sulphate

t = filtration time (min).

τ = the time required for 50% adsorbate breakthrough (min)

t = the time (min)

τ = the tortuosity

v = the linear velocity (cm/min)

V = volume of the solution (L)

Z = the bed depth of column

ABSTRACT

Wastewater treatment is an imperative requirement in order to meet effluent quality standards before wastewater can be discharged directly into the rivers, streams and the ocean. Together with the rapid development of industry and society, large volumes of wastewater with hundreds of toxins and impurities, if not treated properly, can severely affect humans and environmental health through different manners such as drinking water contamination and habitat degradation. In particular, the excessive presence of phosphate in water encourages the growth of algae that then leads to eutrophication. Thus, wastewater treatment systems, including phosphate removal, are considered to be a principal tool to reduce the negative effects of wastewater.

The main objectives of this study were to evaluate (i) the capabilities of two commercial ion exchange resins - Purolite A860S, Dowex 21K XLT and a low cost adsorbent - steel furnace slag (SFS) on phosphate removal, and (ii) the effect of modification of these materials on phosphate removal capacities. In this study, two modified materials, Dowex 21K XLT_Cu and modified steel furnace slag (M-SFS) were developed from original Dowex 21K XLT and steel furnace slag respectively.

The performance of these ion exchange resins on phosphate removal was evaluated in different experimental conditions such as varying adsorbent dose, initial adsorbate concentration, contact time and pH in a series of batch studies. The Langmuir and Freundlich models were found to fit with the experimental data of all resins and slag. The results also show that the modification of ion exchange resin and slag led to a significant improvement of phosphate removal efficiency.

The maximum phosphate adsorption capacities for Dowex 21K XLT_Cu, Dowex 21 K XLT and Purolite A860S were 97.09; 65.35 and 52.63 mg/g respectively. The adsorption kinetic of these resins was also fitted well with the Pseudo-Second-order kinetic model (R^2 = 0.99). The breakthrough data was reasonably described by using two empirical models: Thomas and Yoon-Nelson ($R^2 \geq 0.93$). Phosphate adsorbed by resin was effectively desorbed by using 0.5M NaOH. The adsorbent capacity of resin was found to be recovered well after three adsorption/desorption cycles.

This study also investigated the phosphate adsorption capacity of low cost materials, SFS and M-SFS. The phosphate adsorption capacities of SFS and M-SFS were 22.88 and

30.49 mg/g respectively, lower than those of the resins. For SFS and M-SFS, Langmuir isotherm model gave a better fit than the Freundlich model. The results also revealed that Thomas model can be used to describe the behaviour of the phosphate adsorption on SFS and M-SFS in the filter column test.

In conclusion, the results show that Dowex 21K XLT_Cu was the most effective adsorbent for Phosphate removal. It can be regenerated and reused effectively. When the treatment cost is considered, SFS and M-SFS could be the potential adsorbents.