Mozambican Adsorbents for Zinc (II) Removal in Aqueous Solutions

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Abstract The chapter presents a study of the adsorption capacity of zinc ions from aqueous solutions in natural adsorbents (bagasse ash of red variety sugarcane, coconut shell, activated carbon, and bentonite) from Mozambique. As a heavy metal, zinc has maximum allowable concentration in the drinking water of 5 mg/L according to the Mozambican norm. The environmental pollution caused by the discharge of effluents with contents outside the dumping regulations of Mozambique can be reduced by the use of local materials. According to the results of kinetic studies, the models which better adjust were the pseudo-second order which indicate a physical-type adsorption. Bagasse ash of red variety sugarcane presented the higher adsorption capacity while coal had the lower capacity.

Keywords Adsorbents · Zinc · Adsorption · Kinetic model

1 Introduction

Zn (II) ion is an essential micronutrient and, in general, is considered one of the elements less dangerous. For humans, the feeding sources of zinc are mainly oysters, animal's livers, beer yeasts, meat, and vegetables [5]. The concentration of

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Zinc in drinking water is low and varies from 0.01 to 1 mg/L. If there are favorable conditions, the gastrointestinal absorption is 20–30% [4]. Thus it is favored by cysteine, methionine and histidine amino acids, sugars like fructose and lactose, and vitamin C. On the contrary, it is hindered by high doses of phosphorus, copper, manganese, iron, and tin. Zinc accumulates in the liver, pancreas, kidneys, and prostate [2].

The presence of zinc in a wide variety of enzymes demonstrates its important role in metabolism. The Food and Nutrition Board of the National Academy of Sciences recommends a daily intake of 15 mg of this element for adults. Its lack causes growth decline, marked hypogonadism, and rough and dry skin [2].

Despite being an essential element, at high dosages can be toxic for humans. Among others, toxicity symptoms include vomiting, dehydration, electrolyte imbalance, abdominal pain, lethargy, dizziness, and loss of muscle coordination. Daily doses of 150 mg interfere with the metabolism of copper and iron [2]. The chapter presents possibility to the lower concentrations of this ion in water, by removing it using bagasse ash of Mozambique red variety sugarcane as adsorbent.

Problem: Environmental pollution caused by the discharge of effluents with contents outside the dumping regulations of Mozambique.

General objective: Characterize and use the bagasse ash of red variety sugarcane, coconut shell, chemically activated carbon, and bentonite of Mozambique as sorbent for zinc removal in model solutions.

2 Materials and Methods

The bagasse ash used was obtained under preset thermal conditions, and the Mozambican coconut shell carbon was obtained by treatment with phosphoric acid 0.6 mol/L and bentonite of Boane region. These materials are characterized from the physical point of view by the determination of pycnometric densities, apparent, apparent by imprisonment, tortuosity, compressibility, and porosity. The determination of the specific surface is possible. In the case of activated carbon, it is necessary to set a series of characteristic parameters for this type of material.

The kinetic of sorption process is evaluated by absorption atomic method. In this study, silicate is brought into contact with known concentration of zinc (II) nitrate solution, for a certain time, to obtain the concentration values of Zn (II) ions at time intervals.

The results obtained from this method are evaluated with the following different kinetic models [1, 3]:

- Pseudo-first order (PFO),
- Pseudo-second order (PSO),
- Elovich model (EM),
- Intraparticle diffusion (DIP).

Related equations are presented below:
Pseudo-first-order model

$$\ln(q_e - q_t) = \ln q_e - k_1 t \quad (1)$$

Pseudo-second order

$$t/q_t = 1/k_2 q_e^2 + t/q_e \quad (2)$$

Elovich model

$$q_t = \alpha + \beta \ln t \quad (3)$$

Intraparticle diffusion model

$$q_t = k_d t^{1/2} \quad (4)$$

where

q_e	quantity of sorbed metal at equilibrium (mg/g)
q_t	quantity of sorbed metal at any time (mg/g)
t	time (min)
k_1	pseudo-first-order velocity constant (min^{-1})
k_2	pseudo-second-order velocity constant (g/mg min)
k_d	intraparticle diffusion velocity constant (mg/g $s^{1/2}$)
α	initial sorption velocity (mg/g min)
β	desorption constant (g/mg)
C_e	concentration of solute at equilibrium (mg/L)
C_o	solute initial concentration (mg/L)
a	constant related to thermal adsorption
k_{ads}	first- and second-order adsorption velocity constant
m	sorbent mass
V	volume of the solution.

3 Analysis of Results

- Bagasse ash of sugarcane characterization
  The bagasse ash of sugarcane used, obtained, has a series of characteristics that are exposed in Table 1.
- Characterization of the coconut shell powder
  The results obtained in the coconut shell powder characterization tests are summarized in Table 2.

Table 1 Sugarcane bagasse ash physic parameters

Parameter	Values
Apparent density	0.62 g/mm^3
Apparent density by imprisonment	0.76 g/mm^3
Pycnometric density	2.3126 g/mm^3
Porosity	73.2%
Compressibility	18.4%
Flow rate	0
Sphericity	0.45
Specific surface	19.863 m^2/g
Tortuosity	1.38

Table 2 Coconut shell powder physic parameters

Parameters	Values
Apparent density	0.15 g/mm^3
Apparent density by imprisonment	0.28 g/mm^3
Pycnometric density	0.418 g/mm^3
Flow rate	0
Tortuosity	1.85
Compressibility	46.64%
Porosity	63.88%
Specific surface	122.32 m^2/g
Relative humidity	8.8%

- Characterization of coal obtained from coconut shell
  Coal obtained from coconut shell has characteristics presented in Table 3.
- Characterization of bentonite
  Below in Table 4 are the results of the bentonite used.
- Kinetic studies
  The results of the kinetic study are shown below in Table 5.

In general terms, the pseudo-second-order model is adjusted to the four adsorbents. However, the Elovich model for bentonite predicts the overlap of a chemical interaction between adsorbate and adsorbent. The adjustment of the diffusional model for bentonite is noteworthy given the high value of the bilinear correlation coefficient obtained.

Below in Table 6 are the values obtained from the parameters corresponding to pseudo-second-order model.

It is worth mentioning the diffusional model in bentonite, where the diffusivity of the zinc (II) ion is 7.52×10^{-14} m^2/s, value within the order for ions that do not have an accentuated polarizability.

Table 3 Coconut coal physical parameters

Parameters	Values
Apparent density	1.07 g/mm^3
Apparent density by imprisonment	1.85 g/mm^3
Pycnometric density	2.726 g/mm^3
Flow rate	0
Tortuosity	0.93
Compressibility	73%
Porosity	49%
Specific surface	219.25 m^2/g
pH	3.5
Volatiles (mf)	22.8
Fixed carbon (mf)	0.6
Ash (mf)	50.6
% Oxygen (maf)	1.5
% Hydrogen (maf)	47.3
% Nitrogen (maf)	1.3

mf: moisture free; maf: moisture and ash free

Table 4 Physic parameters of the bentonite used

Parameters	Values
Apparent density	0.72 g/mm^3
Apparent density by imprisonment	1.05 g/mm^3
Real density	1.8256 g/mm^3
Porosity	60.44%
Compressibility	31.43%
Flow rate	0
Sphericity	0.45
Specific surface	0.056 m^2/g
Tortuosity	1.79

Table 5 Bilinear correlation coefficients for each adsorbent

Model	Ash	Powder	Coal	Bentonite
PFO	0.978	0.952	0.969	0.954
PSO	0.996	0.994	0.995	0.998
EM	0.988	0.979	0.964	0.996
DIP	0.964	0.928	0.919	0.998

Table 6 Parameters of the equation of the pseudo-second-order model

Parameters	Ash	Powder	Coal	Bentonite
h (mg/g min)	14.93	0.004	0.708	2.732
k_2 (g/mg min)	0.51	5.95	3.658	0.35
$t_{1/2}$ (min)	0.36	6.06	0.62	1.02
q_e (mg/g)	5.41	2.34	0.44	2.79

h: Initial velocity
k_2: Apparent constant of reaction rate
$t_{1/2}$: Half-life time
q_e: Adsorptions capacity at equilibrium

4 Conclusions

1. The kinetic model of pseudo-second order is adjusted to the adsorption of the zinc (II) ion in the adsorbents sugarcane bagasse ash, coconut shell powder, chemically activated coconut coal, and bentonite from the Boane region in Mozambique, which advocates a physical-type adsorption.
2. The maximum adsorption capacity of the zinc (II) ions, the maximum initial velocity, and the shortest half-life are represented by the bagasse ash of sugarcane variety Roxa, while coal is the worst of the adsorbents used.

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