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KINETIC AND EQUILIBRIUM STUDIES OF VANADIUM BIOSORPTION BY A BROWN SEAWEED – IMPLICATIONS TO BIOREMEDIATION OF CONTAMINATED SITES

ANTONIO CARLOS AUGUSTO DA COSTA*, MARCELO DE SOUZA OLIVEIRA AND ADERVAL SEVERINO LUNA

Universidade do Estado do Rio de Janeiro, Instituto de Química, Programa de Pós-graduação em Engenharia Química, R. São Francisco Xavier 524, Maracanã, Rio de Janeiro, CEP: 20550-013, Brasil.

ABSTRACT

This paper studied the biosorption of vanadium ions by the brown seaweed *Sargassum filipendula*. Results obtained indicated that acidic pH values are more favorable to biosorption and that the uptake capacity of the biomass gradually increased with the increase of solid/liquid ration. Additionally it was observed that a rapid equilibrium was reached between solid and liquid fractions, around 20 minutes and that the kinetic behavior could be better explained by a second order reaction. Equilibrium data obtained showed that the results could be fit to Langmuir model, indicating that a monolayer of vanadium was probably formed on the surface of the seaweed. These results opens the possibility of using biosorption as a bioremediation technique for large-scale purposes with the use of fixed-bed reactors.

Keywords: Biosorption, Vanadium, Equilibrium, *Sargassum*, Kinetics

INTRODUCTION

Vanadium is a metal element increasingly used in industry. Some substances containing vanadium are used as important catalysts in processes for the manufacture of contact sulfuric acid, as oxidation catalyst in the synthesis of maleic and phthalic anhydrides, in the production of polyamides such as nylon, and the oxidation of organic substances such as ethanol acetaldehyde, sugar and oxalic acid, anthraquinone and anthracene.

World consumption of vanadium pentoxide as floats with the steel industry, but it is estimated between 50 and 60 thousand tons per year. South Africa holds 40% of world production, followed by China, Russia, Australia and USA. It is estimated that the use of vanadium possibly could be increased by use of vanadium redox batteries responsible for the additional consumption of 10,000 tonnes per year. In Brazil, vanadium deposits of minerals can be found in northeastern Bahia State. In addition to these applications, vanadium is used in high strength steels, in a mixture of iron and aluminum.

Brazil has recently established a plant with capacity to produce 5,000 tons of iron-vanadium from the ore extracted in Bahia State. This will put Brazil in the setting of world production of vanadium. Brazil demands 1.2 million tons per year. The extraction process of vanadium demands around 375 m^3/h of water in the process of transformation of the raw ore into iron-vanadium, utilities and leaching. Part of this water will be recycled by the plant itself and another part will be treated and discarded, justifying the need for treatment of bleach in the procedure.

There are negatively charged, neutral and positive vanadium species. The species with negative charge or no charge are not retained by *Sargassum filipendula*. In the case of charged species, the alginate present in the cell structure, and these negatively charged species ($H_2V_{10}O_{28}^{4-}$;

$H_2VO_4^-$; $H_3V_2O_7^-$; H_3VO_4; $HV_{10}O_{28}^{5-}$; $HV_2O_7^{3-}$; HVO_4^{2-}; $V_{10}O_{28}^{6-}$; $V_2O_7^{4-}$; $V_3O_9^{3-}$; $V_4O_{12}^{4-}$; VO_4^{3-}; $V(OH)_3$) will interact.

A study in the United States, in the Environmental Science Laboratory, established in 2010 at 0.33 mg L^{-1} as an acceptable limit for the presence of vanadium in drinking water (US Department of Energy, 2010). Humans when exposed to vanadium pentoxide suffer irritation of the upper respiratory tract, bronchi, lungs and skin. Acute intoxication can cause systemic symptoms. Repeated exposure can lead to chronic bronchitis. Workers exposed to a concentration of 1.5 mg L^{-1} develop dermatitis, as well as conjunctivitis and tracheobronchitis (US Department of Labor, 2012).

Seaweeds have a high content of biopolymer which may bind the heavy metals and require less critical conditions than those required by micro-organisms during the fermentation. *Sargassum filipendula* has been the object of study in recent years for their ability to retain heavy metal ions from aqueous solutions. Structure of their cell wall present cellulose, the wall structure, alginic acid responsible for ion-exchange and sulfated polysaccharides. The last two functional groups present a key role in the process of biosorption. Brown algae are the most common algae on the Brazilian coast and *Sargassum* beds are ecologically important for harboring a wealth of species of marine flora and fauna (Ferreira et al., 2011. Henriques et al. (2011) conducted study of kinetics, equilibrium and dynamic biosorption of Mn (II) by *Sargassum filipendula* biomass and Ferreira et al. (2011) conducted the study of thorium and uranium biosorption by *Sargassum filipendula*. This paper proposes a treatment for aqueous leachates contaminated with vanadium using the seaweed *Sargassum filipendula* as biosorbent material. Specifically it was evaluated the effect of pH on the biosorption of vanadium by the biomass as well as the importance of the ratio liquid/solid, the effect of agitation speed and kinetic aspects and balance regulating the process.

MATERIALS AND METHODS

1. BIOMASS

The brown seaweed *Sargassum filipendula* was chosen as biosorbent material based on work done previously (Ferreira et al. 2011; Henriques et al., 2011). The alga was collected on the northeast coast of Brazil and washed with water to remove particulate contaminants. After washing, the biomass was kept at room temperature to remove excess water and then dried for 24 hours at 60°C. The dried biomass was cut, ground and with 0.3 to 0.7 mm fraction was separated by a series of Tyler sieves and selected for testing of biosorption in a batch system.

2. VANADIUM SOLUTIONS

The solutions for biosorption batch tests were prepared by dissolving the vanadium pentoxide in distilled water in the presence of 1.0 mol nitric acid L^{-1}. For the batch test for the establishment of proper pH for biosorption, the best solid/liquid ratio, proper agitation speed and kinetic studies, were prepared solutions containing vanadium in concentrations of 20.0 and 90.0 mg L^{-1}, 40.0 and 90.0 mg L^{-1}, 40.0 and 90.0 mg L^{-1}, respectively. To study the equilibrium solutions were used containing vanadium concentrations from 25.0 to 780.0 mg L^{-1}. After filtration, vanadium solutions were quantified by optical emission spectrometry by inductively coupled plasma, Model Ultima (Jobin Yvon - Horiba).

3. DETERMINATION OF THE OPTIMAL Ph FOR BIOSORPTION OF VANADIUM BY S. filipendula

The study of optimum pH for biosorption of the vanadium by *S. filipendula* was performed to identify conditions that favor the biosorption of vanadium and at the same time does not ensure chemical precipitation. Were prepared twelve bottles of 250.0 mL polypropylene, where to 6 of them it was added 0.100 g of seaweed and 25.0 mL of vanadium in a concentration of 20.0 mg L^{-1}, varying the pH from 1.0 to 6.0. To the other six flasks were added 0.100 g of seaweed and 25.0 mL of vanadium in a concentration of 90.0 mg L^{-1} also at pH 1.0 to 6.0. The flasks were incubated on a rotary shaker (Tecma, model TE-370) for 2 h at 150 rpm and 30°C, respectively (da Silva, 2010 and Reis 2008).

4. DETERMINATION OF THE SOLID/LIQUID RATIO IDEAL FOR THE BIOSORPTION OF VANADIUM BY S. filipendula

For this experiment were prepared three bottles of 250.0 mL with the following amounts of dry biomass: 0.050, 0.100 and 0.150 g and, to each bottle it was added 25.0 mL of vanadium in a concentration of 40.0 mg L^{-1}. The same procedure was repeated for a solution of vanadium in a concentration of 90 mg.L^{-1}. The flasks were incubated on a rotary shaker, at 150 rpm, at pH 2.0 for 2 hours.

5. DETERMINATION OF THE OPTIMAL AGITATION RATE FOR THE BIOSORPTION OF VANADIUM BY S. filipendula

Ten Erlenmeyer flasks were prepared of 250.0 mL with 0.100 g of biomass, where in each was added 25.0 mL of vanadium in a concentration of 40 mg.L^{-1}. With the pH set at 2.0 and the contact time of 2 hours, one can vary the speed to 50, 100, 150, 200 and 235 rpm. After 2 hours of contact the vials were removed from the rotary shaker to determine the equilibrium concentration of vanadium, as described above.

6. KINETIC STUDY

For kinetic studies were prepared 10 Erlenmeyer flasks of 250 mL with 0.100 g of biomass and 25.0 mL of vanadium in a concentration of 18.0 mg L^{-1} with the pH adjusted to 2.0 and 10 Erlenmeyer flasks with 0.100 g of biomass and 25.0 mL of vanadium in a concentration of 36.0 mg L^{-1} with the pH adjusted to 2.0. The samples were placed in a rotary shaker (Tecnal TE 420, Brazil) with temperature adjusted to 30°C and 150 rpm. After the contact time the bottles were removed from the rotary shaker at varying intervals of time, the latter Erlenmeyer flask removed after 2 h.

The data obtained in this study batch can be used to determine the time required to reach equilibrium, thereby developing the predictive models for testing in a continuous system and knowledge of the variables that influence the process.

Models pseudo-first order (Lagergren) and second order are more commonly used in conventional adsorption systems, having been used in this study.

6.1 Lagergren pseudo–first Order Model

The Lagergren model was the first to be developed for a sorption process of a solid-liquid and has been widely applied to various adsorption systems. The model is represented by the following expression (1):

$$\frac{dq}{dt} = k_{1,ad}(q_e - q_t) \text{, onde:} \quad (1)$$

where:

q - amount of metal accumulated in the biomass (mg g^{-1})

q_t - amount of metal retained at time t (mg g^{-1})

$k_{1,d}$ - the reaction rate constant for pseudo first-order

Integrating and linearizing this equation we arrive at (2), allowing the calculation of kinetic constants of the model:

$$\ln(q_e - q_t) = \ln q_e - k_{1,adx} \times t \quad (2)$$

6.2 Second Order Model

The second order model can be expressed by (3):

$$\frac{d_q}{d_t} = k_{2,ad}(q_e - q_t)^2 \quad (3)$$

Where:

$k_{2,ad}$: rate constant of second-order reaction (g.mg^{-1}.min^{-1}). Integrating the equation we arrive at (4):

$$\frac{t}{q} = \frac{1}{k_{2,ad} \times q_e^2} + \frac{1}{q_e} \times t \qquad (4)$$

In its linear model also allows the calculation of constants typical model.

7. VANADIUM BIOSORPTION ISOTHERMS

To study the equilibrium, operating conditions used were similar to those used in the kinetic studies, however, the initial concentrations of vanadium ranging from 25 to 700 mg L^{-1}.

The experimental data obtained from balance trials with vanadium have been adjusted by applying the models of Langmuir and Freundlich isotherms linearized.

The biosorption can be evaluated quantitatively by the adsorption isotherms. They express the relation between the amount of metal that is adsorbed per unit weight of biosorbent and the concentration of metal in the solution in equilibrium at a given temperature. In this dissertation, the metal in question is vanadium and biosorbent used was *S. filipendula*.

The equilibrium is established by contact between the solution charged with metal biosorbent at a constant temperature. A certain amount of the metal adsorbed by the biomass is in equilibrium with the residual metals in solution. A graphic representation of the isotherm is usually represented by a hyperbola, expressing the metal removal by biosorbent (weight/weight or mole/w) depending on the residual concentration (mass/volume).

The removal capacity Q (mg g^{-1}) is given by equation (5):

$$q = \frac{V(C_e - C_i)}{s}, \qquad (5)$$

where:
q - amount of metal removed (mg metal g biosorbent^{-1})
V - volume of solution loaded with the metal of interest
C_i - Initial concentration of the metal in solution
C_e - residual concentration of metal in the final solution
s - mass of the biosorbent

There are different models of adsorption isotherms, ranging from simple equations to more complex ones, they are: Langmuir, Freundlich, Brunauer-Emmett-Teller (BET), Dubunin-Radushkevich, Radke and Prausnitz, Reddlich Peterson, all with the goal of describe the biosorption system. The models most commonly used are the Langmuir and Freundlich.

7.1 Langmuir Model

The Langmuir model considers that the molecules are adsorbed and adhered to the surface of the adsorbent on defined sites and located in an homogeneous adsorption, being represented by equation (6):

$$q = \frac{q_{\max} k C_e}{1 + k C_e}, \text{ onde:} \qquad (6)$$

where:
q - amount of metal biosorbent retained by the balance (mg g^{-1} or mmol.g^{-1})
q_{max} - maximum accumulation (mg g^{-1} or mmol.g^{-1})
C_e - the final concentration of metal in solution at equilibrium (mg.L^{-1} or mmol.L^{-1})
k - constant indicative of the affinity between biomass and metal

The values of k can be determined q_{max} linear form in the preceding equation, adding up to (7):

$$\frac{Ce}{q} = \frac{1}{q_{\max} k} + \frac{Ce}{q_{\max}} \qquad (7)$$

7.2 Freundlich model

This empirical model system can be amplified to non-ideal conditions, in heterogeneous multilayer surfaces, with the mathematical expression (8):

$$q = k_f C^{\frac{1}{n}} \qquad (8)$$

where:
k_f - constant representing the ability to bind the metals
n - constant representing the intensity of binding to metal
C - concentration of the metal in equilibrium

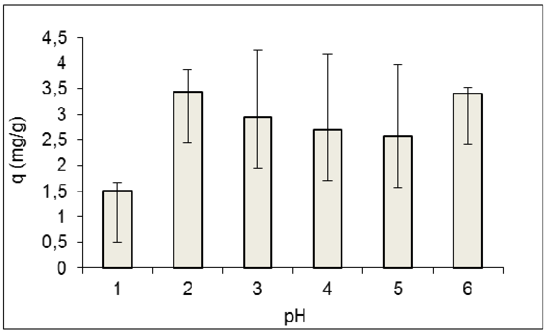
In its linearized form it is possible to calculate n and k_f through the angular and linear coefficients, respectively. Its linearized form is given by (9):

$$\ln q = \ln k + \frac{1}{n} \ln Cf \qquad (9)$$

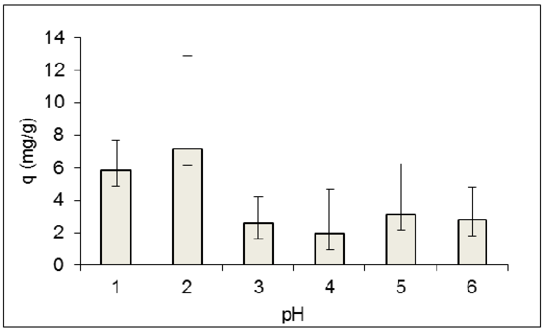
RESULTS AND DISCUSSION

1. DETERMINATION OF THE OPTIMAL pH FOR BIOSORPTION OF VANADIUM BY S. filipendula

Figure 1 *shows the results of determination of the optimal pH of the vanadium biosorption by S. filipendula.*



(a)



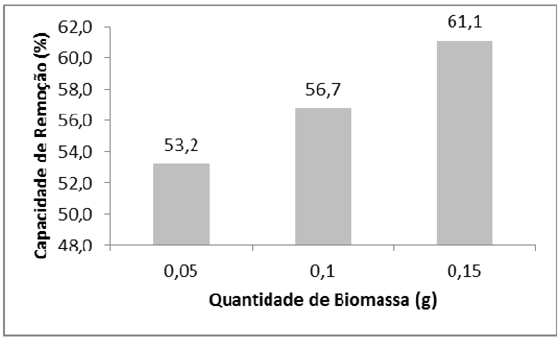
(b)

Figure 1: Effect of pH on biosorption of vanadium per S. filipendula. (a) 0.100 g of biomass, 25.0 mL of vanadium (20.0 mg L^{-1}), temperature 25.0°C and 150 rpm agitation, (b) the same conditions with a solution of vanadium equal to 90.0 mg L^{-1}.

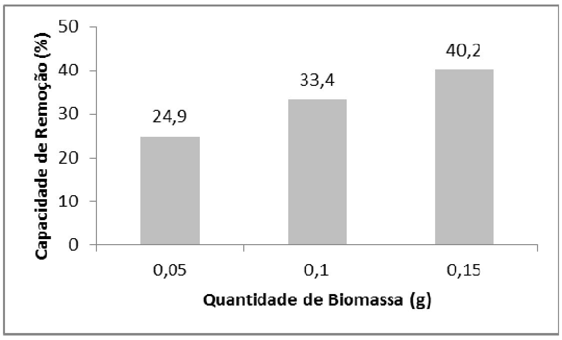
Figure 1 (a) indicates that no significant variation in charging capacity of the biomass in the pH range of 2.0 to 6.0. The values of the respective standard deviations shown in the graph indicate that it is possible to adjust a good capacity for removal of vanadium to that pH range. Therefore, the value of 2.0 was established as the optimum pH for biosorption of vanadium by *S. filipendula*. The results in Figure 1 (b) confirm the pH 2.0 as the most suitable for biosorption of vanadium. However, increasing values of pH for the loading capacity of the biomass does not remained stable as in Figure 1 (a). Volesky (2004) presents a brief review of the chemistry of vanadium, correlating ionic forms, pH and concentration. The vanadium as VO_4^{-3} generates a multivalent metal anion in aqueous solution. For example, at pH 13.0 vanadium (V) is in the form of orthovanadate (VO_4^{-3}). As the pH decreases, other anionic vanadium begin to be formed, such as: $V0_3(OH)^{2-}$, $V_2O_7^{4-}$, $V_4O_{12}^{4-}$, $V_3O_9^{3-}$, $VO_2(OH)^{2-}$, $V_{10}O_{27}(OH)^{5-}$ e $V_{10}O_{26}(OH)_2^{4}$-. At acidic pH range between 1.0 and 4.0 the cationic form predominates VO_2^+, as well as the neutral forms V_2O_5 and $VO(OH)_3$. The distribution of species of vanadium in solution is therefore highly dependent on this parameter to a specific temperature. It is thus important to work in the acidic pH so that, in solution, positively charged species occurs and bioremediation can take place. Ghazvini and Mashkani (2009) observed the effect of salinity on the vanadium biosorption by *Halomonas* sp. GT-83 obtaining a maximum adsorption capacity (91.8%) at pH 3.0, with the equilibrium established in about 2 h to a solution at a concentration of 100.0 mg L^{-1}. The results presented by these authors indicate a match with the pH value within the range set out in this work. In a study presented by Kaczala et al. (2009) has shown a reduction in the initial pH of 7.4 to 4.0 resulting in increases in the uptake from 32% to 99% lead (Pb) and from 43% to 94% vanadium (V), when these were put in contact with sawdust of *Pinus sylvestris*. As those authors have worked with sawdust, results were different in the uptake and optimum pH of 4.0 was established in bioremediation, which shows a correlation with the results of this study, as represented by the trend shown in Figure 1 (a). At pH 4.0 the vanadium species were best biosorbed by *S. filipendula* from the test solutions. Da Silva (2010) presented results for biosorption of thorium and uranium by *S. filipendula*, and obtained 96% and 54% removal of thorium in pH 1.0 and 4.0 respectively, from a solution of 1 mg L^{-1}. The improved uptake efficiency of uranium ions was 33% at a concentration of 100 mg L^{-1} at pH 1.0 and 71% for 1 mg L^{-1} at pH 4.0. In spite of this study have been made for a different metal, it can be seen that the acidic pH range, once again, was applied aiming the formation of species with a positive charge, facilitating the bioremediation.

2. *DETERMINATION OF THE OPTIMAL SOLID/LIQUID RATIO FOR BIOSORPTION OF VANADIUM BY S. filipendula*

Figure 2 shows the results of determining the solid/liquid ratio ideal for the bioremediation of vanadium by *S. filipendula*.



(a)



(b)

Figure 2*: Effect of the ratio liquid/solid for vanadium biosorption by S. filipendula. (A) 25.0 mL of vanadium in a concentration of 40.0 mg L^{-1}, 25.0°C and 150 rpm, (b) the same conditions with a solution of vanadium in a concentration of 90.0 mg L^{-1}.*

For the less concentrated solution of vanadium it can be observed that the metal removal capacity ranged from 53.2 to 61.1% as the amount of biomass increased. As for the more concentrated solution of vanadium, metal removal capacity ranged from 24.9 to 40.2% as the amount of biomass increased. This behavior is expected, since the amount of adsorbent becomes greater for the same amount of vanadium ions to be retained. Thus, it appears that as it increases the amount of biomass increases the ability of metal removal.

Henriques et al. (2011) also obtained good results using an amount of 0.100 g of *S. filipendula* to remove the Mn(II) ion and obtained a removal of 95.7% for an equilibrium reached in 30 minutes at pH 3.0.

3. *DETERMINATION OF THE OPTIMAL AGITATION RATE FOR BIOSORPTION OF VANADIUM BY S. filipendula*

Figure 3 shows the results of the study to determine the optimal agitation speed for biosorption of vanadium.

The stirring rate was studied at only one concentration of vanadium to verify that the mass transfer is not influenced significantly by high agitation speeds (greater than 150 rpm). The results in Figure 3 confirms that for agitation rate above 150 rpm there were no substantial variation in loading of the biomass. Henriques et al. (2011) worked with a constant speed of 150 rpm in the study of Mn(II) ion biosorption by *S. filipendula*. Ferreira et al. (2011) presented results for biosorption of thorium and uranium by *S.*

filipendula, obtained 96% and 54% removal of thorium in pH 1.0 and 4.0, respectively, at 150 rpm. Results here presented confirmed that the stirring speed used in previous studies are in accordance. It also shows that the effect of the stirring speed is not significant for higher speeds until 150 rpm when working with the biosorption of vanadium by the seaweed *S. filipendula*.

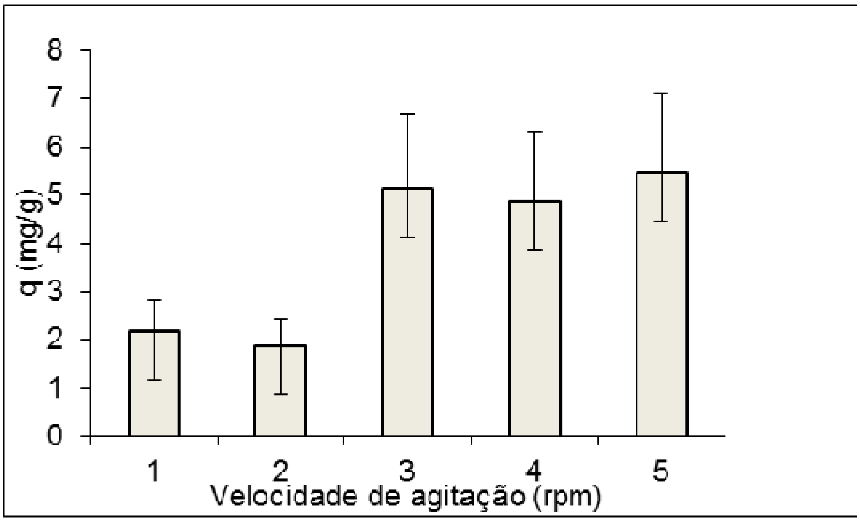


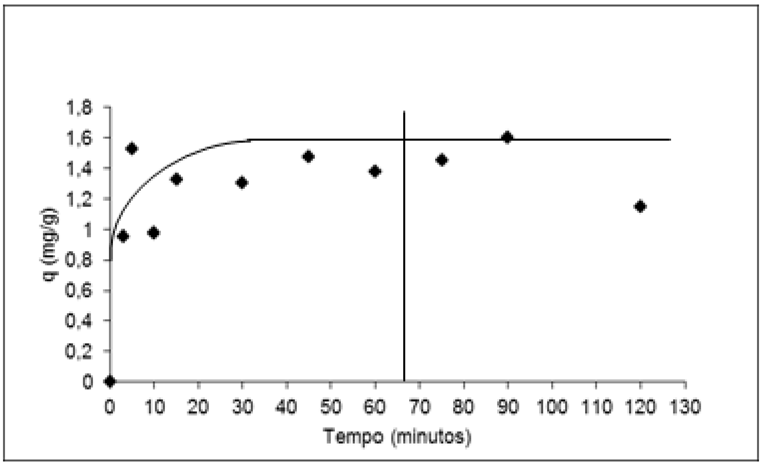
Figure 3: ***Effect of agitation rate on the biosorption of vanadium by S. filipendula. Test conditions: 0.100 g of biomass, 25.0 ml of vanadium equal to 40.0 mg L^{-1}, 25.0 ° C and agitation of: (a) 50 (2) 100, (3) 150 (4) 200 and (5) 235 rpm.***

4. KINETIC STUDY

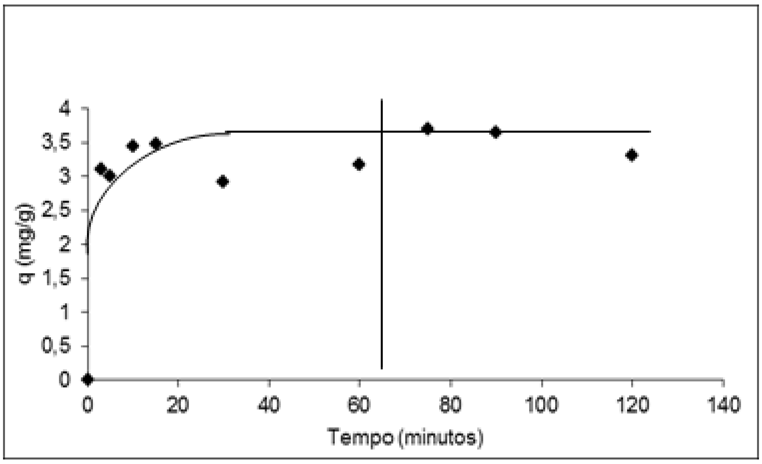
Figure 4 shows the results of the kinetic study conducted with two concentrations of vanadium.

It can be observed that in both cases, the equilibrium occurred after 20 minutes of contact between biomass and the solution of vanadium, a relatively short time to be established. There is therefore a rapid increase in the rate of uptake of metal ion by the biomass in the initial process, and soon after the system reaches equilibrium.

One can also make an estimate of the value of q for both cases: 1.6 mg g^{-1} and 3.5 mg g^{-1} in the concentrations of vanadium of 18.0 and 36.0 mg L^{-1}, respectively. The results of the experimental points set to the model first and second order are shown in Figure 5, and the results for the more concentrated solution in Figure 6.



(a)

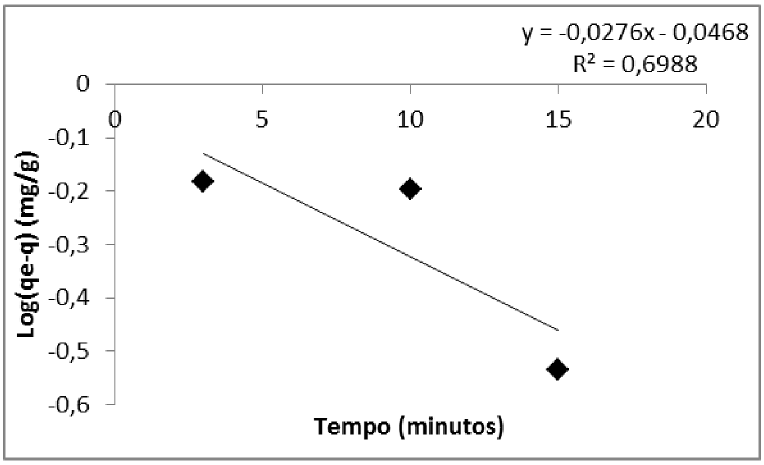


(b)

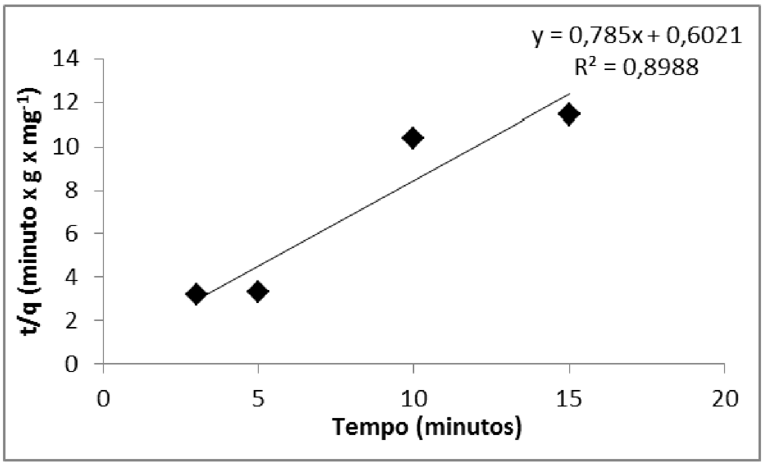
Figure 4: ***Kinetic study of vanadium biosorption by S. filipendula. (a) 0.100 g of biomass, 25.0 ml of vanadium (18.0 mg L^{-1}), 25.0°C and 150 rpm, (b) the same conditions with a solution of vanadium in a concentration of 36.0 mg L^{-1}***

Ferreira et al. (2011) obtained the equilibrium in 150 minutes of contact with the solution of thorium ion at a concentration of 1 mg L^{-1} and pH 1.0. It was observed a rapid uptake of thorium in the first 2 minutes, followed by a slower growth until the stability with the biomass. Under these experimental conditions the maximum metal removal rate was found 98% has been achieved the removal of 73% thorium in the first two minutes. The rapid adsorption of the metal in the first few minutes was due to the greater availability of binding sites initially, reversing this situation until time to reach equilibrium. In the present work, the time needed to reach equilibrium was 20 minutes, with a maximum removal rate of 42%.

Vijayaraghavan et al. (2009) studied the biosorption of lead, copper, zinc and manganese contained in the same solution, where the test conditions were pH 6.0, concentration of biosorbent equal to 3 g L^{-1}, temperature of 23°C and stirring rate of 150 rpm. For zinc and manganese, the equilibrium time was 20 minutes and 50 minutes for lead and copper. These results show that the equilibrium of the heavy metals by biosorption by *Sargassum* changes with the metal in question, but also show a certain degree of agreement with the value found for the vanadium (20 minutes) in this study. The experimental data were tested for two classical kinetic models as described previously.



(a)



(b)

Figure 5: (a) ***Graphical representation of first-order kinetic model. Test conditions: 0.100 g of biomass, 25.0 mL of vanadium equal to 18.0 mg L^{-1}, temperature 25.0 ° C and 150 rpm, (b) Graphic representation of the second order kinetic model (same conditions).***

Table 1 presents the results obtained from mathematical models of kinetics of Lagergren (pseudo-1st order) and 2nd order.

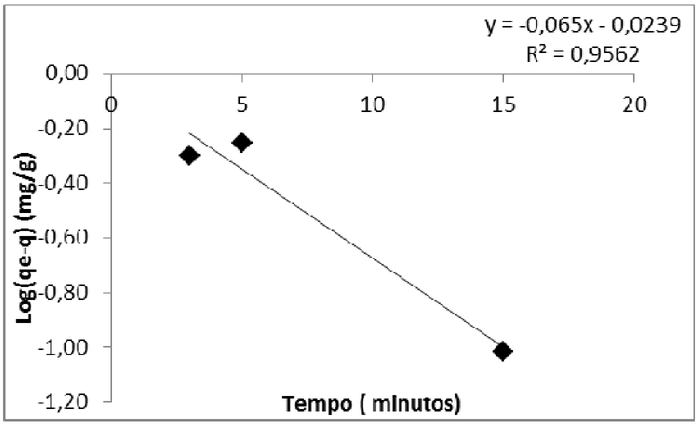
Table 1. ***Results of kinetic study of vanadium biosorption by Sargassum filipendula.***

Lagergren (1st. Order)			2nd. Order		
$K_{1,ads}$	$Q_{máx}$	R^2	$K_{2,ads}$	Q_{max}	R^2
(min^{-1})	(mg g^{-1})		(g mg.min^{-1})	(mg g^{-1})	
0.063 (a)	1.6	0.6988 (a)	0.6487 (a)	1.6	0.8988 (a)
0.1496 (b)	3.5	0.9562 (b)	0.4218 (b)	3.5	0.9825 (b)

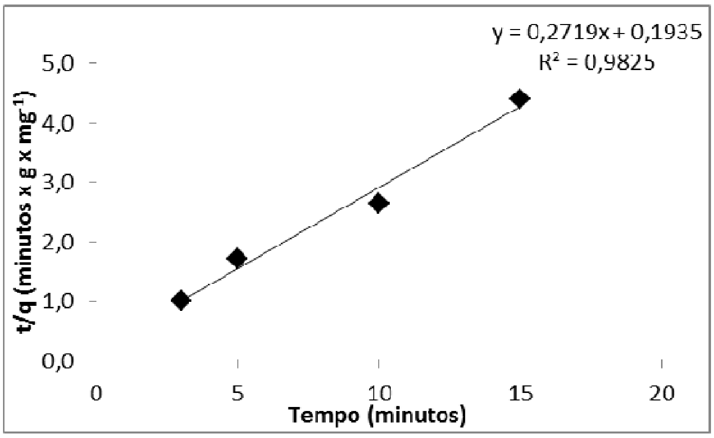
It can be observed that the results for the two concentrations are coincident and show a tendency to adjust to a second order kinetic model for biosorption of vanadium by *S. filipendula*. This fact is highlighted by the best correlation coefficients presented.

Henriques et al. (2011) studied manganese ion biosorption by *S. filipendula* at pH 3.0 and initial concentrations of 150, 575 and 650 mg L^{-1} and concluded that the biosorption process followed the second-order kinetic model.

Ferreira et al. (2011) investigated the biosorption of thorium and uranium by *S. filipendula* and noted that the experimental data of kinetics of thorium showed a better fit for the second order model. However, for the conditions of 10 mg L^{-1}, pH 4.0 the data are more appropriate predicted by the model of Lagergren.



(a)



(b)

Figure 6: (a) ***Graphical representation of first-order kinetic model. Test conditions: 0.100 g of biomass, 25.0 mL of vanadium equal to 36.0 mg L^{-1}, temperature 25.0 ° C and 150 rpm, (b) Graphic representation of the second order kinetic model (same conditions).***

5. STUDY OF EQUILIBRIUM ISOTHERMS

Figure 7 shows the results of the equilibrium model constructed by the Langmuir and Freundlich. Figure 7 (a) showed a profile of increasing uptake of vanadium at pH 2.0 and had a better correlation coefficient. Figure 7 (b), the Freundlich isotherm, showed a profile increasing the uptake of vanadium under the test conditions set out above. However, experimental results that could be applied in this model as the correlation coefficient was low, equal to 0.5419. Table 2 shows the comparative results for the parameters extracted from the Freundlich and Langmuir models.

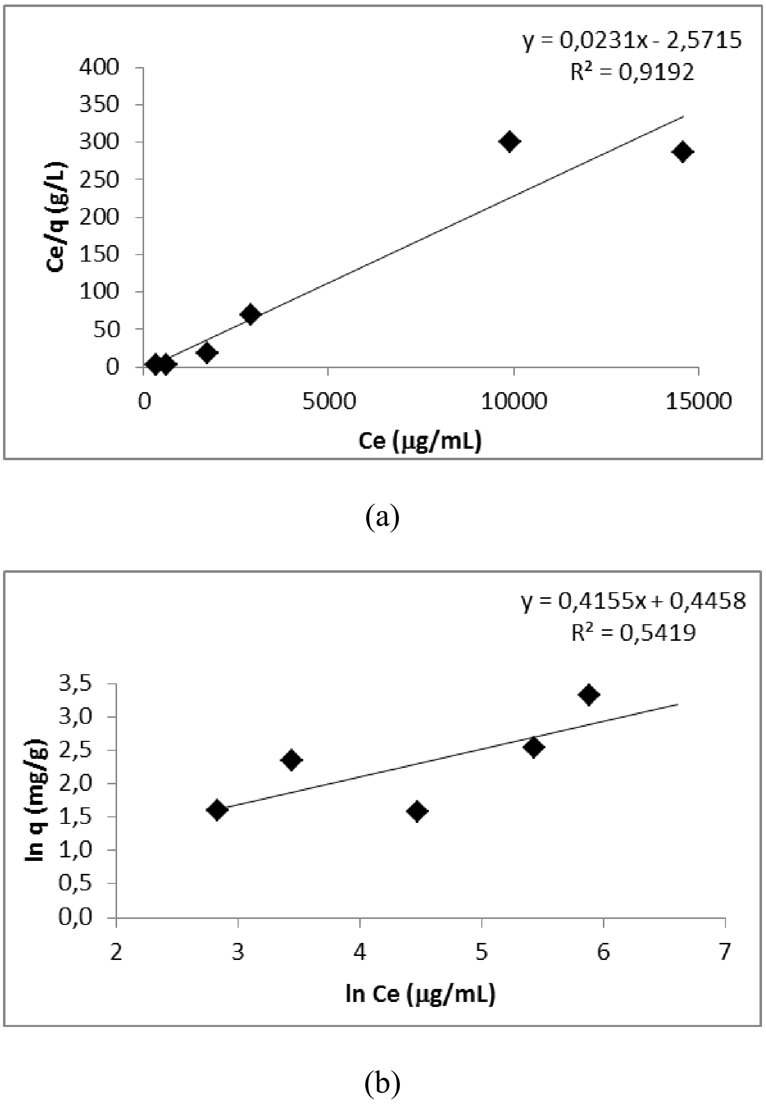


Figure 7: (a) ***Linearized Langmuir isotherm (b) Linearized Freundlich isotherm***

Table 2. ***Equilibrium parameters obtained from fitting the experimental data to Langmuir and Freundlich isotherms - Biosorption of vanadium by Sargassum filipendula.***

Freundlich			**Langmuir**		
K_f	n	$\mathbf{R^2}$	Q_{max} (mg g^{-1})	b (L mg^{-1})	$\mathbf{R^2}$
1.56	2.41	0.5419	43.3	0.009	0.9192

The value Q_{max} reflects the maximum amount of metal biosorbed and the value of "b" reflects the affinity of biomass for metal ion analysis. In this case the value found is not very high, but one of the few studies reported by biosorption vanadium Vijayaraghavanet al. (2009) showed a value of 0.0014 for the constant "b". The value of correlation coefficient indicates a good suitability of points for the mathematical model, so that this set of results corroborate the choice of the Langmuir isotherm for the representation of experimental data.

Vijayaraghavan et al. (2009) found values of Q_{max}: 214.0, 67.5, 24.2 and 20.2 mg g^{-1} and b values: 0.0014, 0.0296, 0.0534 and 0.0268 for lead, copper, zinc and magnesium, respectively. These authors also worked with *Sargassum* biomass and obtained different results for each metal, proving once again that the process of biosorption of metals depends on the different characteristics of the system seaweed-metal ion.

The isotherms presented in this paper demonstrate the ability of vanadium removal by *S. filipendula* and showed Q_{max} values, to meet real situations where it is necessary to implement legislation for effluent treatment. With these preliminary results obtained in batch condition it is possible to advance the search for a system using a continuous fixed-bed reactor, which should become the next stage of this research.

6. CONCLUSIONS

Biosorption of vanadium by *S. filipendula* showed better results at pH 2.0. The study showed that the metal removal capacity increases with the amount of biomass present in solution. There is no significant differences in biosorption at the speeds of 150, 200 and 235 rpm. For practical purposes, it is suggested to work always at a speed of 150 rpm, since diffusional problems have not been observed; The kinetics model of second order and the Langmuir isotherm are more appropriate in the elucidation of vanadium biosorption by *S. filipendula*.

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