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Adsorptive Performance of Soy Bran and Mustard Husk Towards Arsenic (V) Ions from Synthetic Aqueous Solutions

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Received: 10-29-2018

Abstract

Recently, there is growing attention on the use of low-cost sorbents in the depollution of contaminated waters. As a consequence, the present work investigates the potential of soy bran and mustard husk as possible sorbent for the removal of arsenic(V) from residual water. Effects of various operating parameters such as: contact time, pH, initial arsenic concentration, pH, sorbent dose, temperature were investigated to determine the removal efficiency of arsenic(V). Thermodynamic parameters that characterize the process indicated that the adsorption is spontaneous and endothermic. The values for the separation factor, R_L were less than one which confirms that the adsorption process was favorable. Equilibrium data fitted well to the Langmuir model with a higher adsorption capacity of soy bran (74.07 mg g⁻¹) towards arsenic(V) ions than mustard husk (65.79 mg g⁻¹). It was found that the pseudo-second order kinetic model was the best applicable model to describe the adsorption kinetic data.

Keywords: Adsorption; arsenic; isotherm; soy bran; mustard husk

1. Introduction

Arsenic is an element that reaches into the environment from a variety of natural sources (volcanic emission, minerals) and anthropogenic activities (mining activities, burning of fossil fuels and the use of arsenical pesticides which have a longer residence time and also an increased capacity of accumulation.^{1–4}

Also, by erosion, decomposition and due to the action atmospheric factors, arsenic can be released into groundwaters and surface waters.^{5,6}

Stable inorganic arsenic species in water include arsenic acid anions ($H_2AsO_4^-$, H_3AsO_4 , $HAsO_4^{2-}$ şi AsO_4^{3-}). Arsenious acid is also stable in water as H_3AsO_3 and $H_2AsO_3^-$ in moderately reducing conditions (< 200 mV).

Inorganic arsenic in oxidation states +V (arsenate) and +III (arsenite) is found in a variety of mineral in natural waters. Chemical arsenic behavior is related to the ease transformations between +III and +V oxidation states. The oxidation state affects the toxicity of arsenic compounds.

The toxicity of different arsenic species decreases in the order arsenite > arsenate > monomethylarsonate > dimethylarsinate).^{8,9}

There is clear evidence that chronic exposure to inorganic arsenic increases the risk of cancer. ¹⁰ Studies have shown that inhalation of arsenic leads to an increased risk of lung cancer whereas the ingestion of arsenic has been associated with an increased possibility of skin cancer and cancer of the bladder, liver and lungs. ^{11,12}

Because of that in 2006 the World Health Organization (WHO) has decided to change the maximum admissible concentration of arsenic from 0.05 mg/L to 0.01 mg/L in drinking water.¹³

In order to eliminate arsenic from water has been used various methods: *i) precipitation/co-precipitation,* (method that allows the removal of arsenic up to 0.05 mg/L and in some cases even less than 0.01 mg/L)^{14,15}; *ii) membrane filtration* (that may remove a variety of contaminants from water but for arsenic compounds this method can reduce their concentration up to 0.05 mg/L.¹⁶ Howev-

er, this method presents some disadvantages, such as low efficiency, large amounts of waste and high cost, as well¹⁶; *iii) ion exchange* (method that are nowadays frequently used in the treatment of containing arsenic groundwater and drinking water because of its of high efficacy advantage.^{1,13,14,16–21} By using this method the level of the arsenic compounds in water is less than 0.01 mg/L.

By adsorption, the contaminants are concentrated at the sorbent surface. Nature of the adsorption process could be explained based on two theories: one physical and one chemical.

Physical theory, the most widespread theory is the so-called potential theory or concentrated layer theory according to which the reaction between atoms that are found on the surface of the solid (adsorbent) and adsorbed molecules is determined by the van der Waals forces of attraction. Chemical theory of the adsorption admits the existence of a single monomolecular layer on the surface of the solid (adsorbent); adsorption forces act only on a very short distance which not exceeding the diameter of a molecule.²²

Thus, the adsorbent material must fulfill certain conditions such as: a type of particle size, high adsorption capacity, high selectivity, and high degree of adsorption, water strong physical connection, and low price.

In recent times, more attention is paid to cheap biomass such as powdered eggshell,²³ pine leaves,²⁴ rice husk.²⁵

These biomasses appear to be a possible alternative for heavy metals removal due to their economic and environmental characteristics, the chemical composition, availability, low price, and high efficiency in removal of heavy metals from dilute solutions.

Recently, the need for an economical method for the removal of pollutants from contaminated waters involves researches on low cost sorbents such as agricultural waste by-products. In this regard, various type of agricultural waste by-products such as palm oil fruit shell,²⁶ coffee grains,²⁷ fir tree sawdust,²⁸ rose petals,²⁹ rice husk,³⁰ cellulose dust³¹ etc. have been investigated for the removal of the pollutants from the wastewaters.

The agricultural by-products may be different parts of plant, such as bark, stem, leaves, root, flower, fruit biomass, husk, hull, shell and may contain compounds such as cellulose, lignin, hemi-cellulose. These compounds have potential functional groups such as hydroxyl, carboxyl, amino, amido and alkoxy with a great affinity for the metal ions.³²

The aim of the present study is to analyse the sorption capacity of mustard husk soy bran as low cost agricultural by-products towards arsenic(V) ions from the residual waters in different experimental conditions. During this study, effect of some parameters such as the dose of adsorbent, pH, temperature, initial metal concentration and contact time were studied. Moreover, various isotherm and kinetic models were used to explain the adsorption process.

2. Materials and Methods

All chemicals were of analytical reagent grade and no further purification was carried out. The agricultural by-products used in these adsorption experiments were soy bran and mustard husk resulting from the milling and baking. Sorbents were collected from a local mill, ground, were prepared and characterized as shown by Humelnicu and colab.³³

The stock solution containing the arsenic(V) was prepared from $\rm Na_2HAsO_4$ $7\rm H_2O$ (Sigma-Aldrich). The adsorption experiments were performed in a batch system by stirring at 350 rpm a suspension that contained arsenic(V) ions solution and the sorbent. The pH values were in range 2 and 10, the initial concentration of the solution varied from 50 to 350 mg $\rm L^{-1}$, at a temperature between of 25 °C – 45 °C, and the sorbent dose varied from 1.5 to 4 g $\rm L^{-1}$. The pH of the solution was adjusted with NaOH or HNO₃ 0.1 M solution and measured with a HANNA pH/temperature meter HI 991001.

After the equilibrium has been reached the supernatant was used for arsenic quantification by using Hydride Generation-Atomic Absorption Spectrometry (HG-AAS). HG-AAS is powerful analytical techniques that provide information of the level of concentrations of As with low interferences and a lower LOQ because the analyte is separated from the sample matrix before the quantification. Experiments were conducted on a High Resolution Continuous Source Spectrometer ContrAA 700 (Analytik Jena).

The amount of arsenic adsorbed per unit mass by the sorbent under equilibrium conditions was calculated by the equation (1).

$$q = \frac{(C_0 - C_e) \cdot V}{m}, \text{ (mg As/g sorbent)}$$
 (1)

where: C_0 is initial concentration of solution, (mg L^{-1}), C_e is equilibrium As(V) concentration (mg L^{-1}), V is volume of solution (L), and m is sorbent mass (g).

The distribution coefficient, K_d , is defined as the ratio of the concentration of arsenic retained in the sorbent and the one in the solution at equilibrium being calculated with equation (2).

$$K_{d} = \frac{(C_{0} - C_{e})}{C_{c}} \cdot \frac{V}{m} \qquad (mL \cdot g^{-1})$$
 (2)

where C_0 , C_e , V and m have the same meaning as in Eq (1).

The adsorption capacities of the two adsorbent were analyzed through the use of Langmuir, Freundlich, Temkin and Flory-Huggins models. The kinetics of arsenic adsorption on the soy bran and mustard husk were analyzed by using pseudo first-order, pseudo second-order, and intra-particle diffusion kinetic models.

Desorption experiments were carried out in batch system by using the sorbent loaded with arsenic immediately after the adsorption processes.

Four common eluents have been tested, namely: NaOH, NaHCO₃, HCl and HNO₃ 0.01 M. The sorbent loaded with As and eluent solution was kept in contact for 24 hours.

The following abbreviations have been used: M-mustard husk, S-soy bran, As-M- mustard husk after As(V) adsorption and As-S-soy bran after As(V) adsorption, respectively.

3. Results and Discussion

3. 1. pH Effect on the Adsorption Process

pH is one of the most important factor that influences the chemistry of arsenic in aqueous solution and surface of the adsorbents. The effect of pH on the adsorption process of As on the mustard husk and soy bran was investigated in the range of values between 2–10. Figure 1 illustrates the effect of pH on As(V) adsorption on the studied adsorbents. The amount of retained As(V) increased slightly with increasing pH and reached a maximum value at pH 6, after that decreased slightly. Consequently, in further experiments pH 6 value was selected as an optimum pH condition.

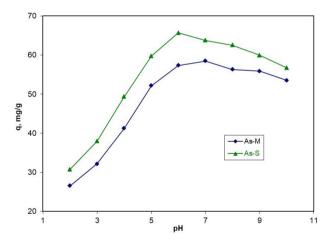


Figure 1. pH dependence of arsenic(V) adsorption on mustard husk and soy bran.

The possible centers on the surface of the sorbents that could be responsible for the adsorption include -OH and -COOH functional groups. Mamindy-Pajany et al. The denotes that in according to the arsenic speciation, $H_2AsO_4^-$ is predominant for pH values between 2 and 5, whereas $HAsO_4^{2-}$ is predominant for pH values between 7 and 10. On the other hand, at higher pH condition active centers were not protonated and were both neutral and anionic by releasing H^+ ions (-COO⁻, -O⁻) which leads to a less adsorption.

3. 2. Effect of Sorbent Dosage

The adsorption process is efficient if it requires a small amount of sorbent. Effect of sorbent dosage on As(V) adsorption was investigated by changing the sorbent dose from 1.5 to 4 g L $^{-1}$ with the initial metal concentration 250 mg L $^{-1}$ at pH 6.0, temperature of 25 °C and contact time 60 min. Figure 2 shows that the adsorption capacity increases with the increase of adsorbent dose from 1.5 to 3.5 g L $^{-1}$ followed by a slightly decrease. Increase of the adsorption capacity was due to the greater availability of the exchangeable sites or surface area at the higher concentrations of the adsorbent.

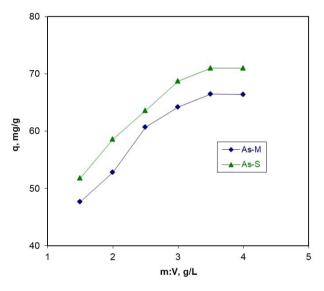


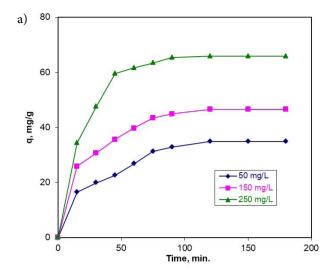
Figure 2. Effect of sorbent dosage on the adsorption process of As(V) on the mustard husk and soy bran.

From the experimental results it was found that the adsorption process has higher efficiency in the case of soy bran as adsorbent in comparison with mustard husk.

3. 3. Effect of Contact Time on the Adsorption Process of As(V)

Influence of the contact time on the adsorption process of As(V) ions on the two sorbents has been studied for a period time between 15 to 180 minutes, all the other parameters being kept constant. In these studies the As ions concentration have been varied from 50 mg $\rm L^{-1}$ to 250 mg $\rm L^{-1}$. The obtained results are depicted in Figure 3.

The results indicate that the amount of the retained ions increases with the increasing of the contact time and the equilibrium is reached after about 75 minutes. From Figures 3 on can conclude that the adsorption of As is more effective on soy bran as adsorbent.



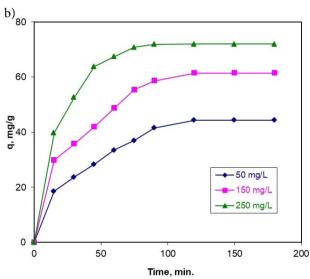


Figure 3. Contact time dependence of adsorption process of As(V) on: a) mustard husk, b) soy bran.

3. 4. Effect of As(V) Initial Concentration on the Adsorption Process

The effect of the initial concentration of the As(V) solution on the adsorption has been investigated, too. The initial concentration was varied from 25 to 350 mg L $^{-1}$, all other parameters have been maintained constant. Figure 4 shows that the adsorption capacity increases with the increasing of the initial concentration of As(V). Thus, for mustard husk adsorption capacity increases form 31.25 to 59.47 mg g $^{-1}$ and for soy bran from 36.98 to 70.39 mg g $^{-1}$. In both cases after 250 mg L $^{-1}$ as initial As(V) concentration the adsorption capacities decrease. These results are in good agreement with Asif and Chen 25 that explained this variation due to a raise in the driving force of the concentration gradient and low concentration, the driving force of adsorbent is reduced due to low concentration gradient. In the diluted solutions the mobility of ions is high, and for

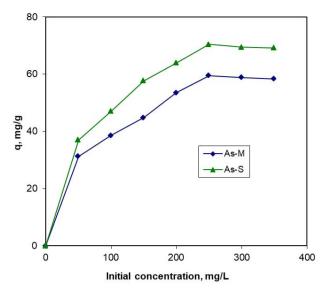


Figure 4. Effect of initial concentration of As(V) on the adsorption process on mustard husk and soy bran.

this reason, the interaction of As(V) ions with the adsorbents was amplified.

3. 5. Effect of the Temperature on the Adsorption of As(V)

The effect of temperature on the adsorption process of the As(V) on the mustard husk and soy bran was investigated from the range of 25–45 °C. All the other parameters have been kept constant and the results are depicted in Figure 5.

Figure 5 indicated that with the increasing of the temperature adsorption capacity of the adsorbents increase due to the increasing of the attractive forces between adsorbents surface and arsenic ions that is typical for the adsorption of most metal ions from their solutions

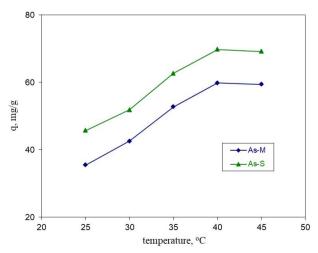


Figure 5. Effect of temperature on the adsorption process of As(V) on the mustard husk and soy bran.

onto natural materials.^{38,39} Rate of the adsorbate's molecules distribution along the external layer, as well as in the internal pores of the adsorbent increases with the increasing of temperature.

3. 6. Thermodynamic Parameters

Determination of the thermodynamic parameters: enthalpy (ΔH^o), entropy (ΔS^o), and free Gibbs energy (ΔG^o), was based on experiments performed in a batch system, at temperatures between 25–45 °C.

For this reason equations (3) and (4) have been applied.

$$\ln K_{\rm d} = \frac{\Delta S^0}{R} - \frac{\Delta H^0}{RT} \tag{3}$$

$$\Delta G^0 = \Delta H^0 - T \Delta S^0 \tag{4}$$

where: K_d is distribution coefficient for adsorption that was calculated with the equation (2).

 ΔH° and ΔS° values have been estimated from the slope and intercept of the plot of lnK_d *versus* 1/T (Figure 6). The obtained results are presented in Table 1.

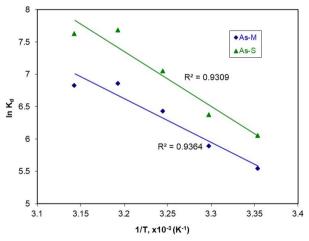


Figure 6. Plot of lnKd function of 1/T.

The data from Table 1 reveal that ΔH^o and ΔS^o have positive values which indicates the sorbent's affinity for arsenic (V) ions and the adsorption is an endothermic process. The positive values of entropy suggest an increase in

the disorder degree in the system. The spontaneity of the adsorption process is confirmed by the negative value of Gibbs energy. This parameter values decrease with the increasing of temperature which indicates the efficiency of adsorption at higher temperature.

The activation energy of the adsorption process (E_a) was obtained from the slope of plotting $ln(1-\theta)$ vs. 1/T, where sorbent surface coverage (θ) was calculated using the equation (Eq. 5):

$$\theta = \left(1 - \frac{C}{C_0}\right) \tag{5}$$

C, C_0 are final and initial concentration of arsenic in aqueous solution (mg/L).

According to the modified Arrhenius equation, 40 the plot of $\ln(1-\theta)$ νs . 1/T gives a straight line with the slope E_a/R . Activation energy values were calculated from the slope of plot and have values of 59.38 kJ mol $^{-1}$ and 31.97 kJ mol $^{-1}$ for mustard husk and soy bran, respectively. The positive values of E_a were consistent with the positive values of ΔH^o and confirm once again the endothermic nature of the adsorption process.

3. 7. Kinetic Models

In order to obtain information on the mechanism of adsorption of arsenic on soy bran and mustard husk three different models were applied, that is: the pseudo-first order model (Eq. 6), pseudo-second order model (Eq. 7) and the intraparticle diffusion model (Eq. 8). A relatively high correlation coefficients value indicates that the model successfully describes the kinetics of arsenic adsorption.

$$\log(q_e - q_t) = \log q_e - \frac{k_1}{2303}t$$
 (6)

$$\frac{1}{q_{t}} = \frac{1}{k_{2}q_{e}^{2}} + \frac{1}{q_{e}}t\tag{7}$$

$$q_{t} = k_{id}t^{1/2} + C_{d}$$
 (8)

where: q_t and q_e and are the amounts of arsenic adsorbed $(mg\ g^{-1})$ at time t and at equilibrium, respectively, k_1 is the rate constant of pseudo-first order kinetic (min^{-1}) , k_2 is the rate constant of pseudo-second order kinetic $(g\ mg^{-1}\ min^{-1})$, and k_{id} is the intra-particle diffusion rate constant $(mg\ mg^{-1}\ min^{-1})$

Table 1. Thermodynamic parameters for the adsorption of arsenic (V) on mustard husk and soy bran.

Sorbent	ΔH°,	ΔS°,	ΔG°, kJ mol ⁻¹						
	kJ mol ⁻¹	J mol ⁻¹ K ⁻¹	25 °C	30 °C	35 °C	40 °C	45 °C		
Mustard									
husk	56.04	234.39	-13.84	-15.01	-16.18	-17.35	-18.52		
Soy bran	70.36	286.27	-14.98	-16.41	-17.84	-19.27	-20.70		

 g^{-1} min^{-0.5}). The plot of $log(q_e - q_t)$ vs. time (Figure 7) give a linear relationship from which k_I and q_e can be determined from the slope and intercept, respectively.

The plot of (t/q_t) vs. time (Figure 8) gives a linear relationship from which q_e and k_2 can be determined from the slope and intercept of the plot, respectively.

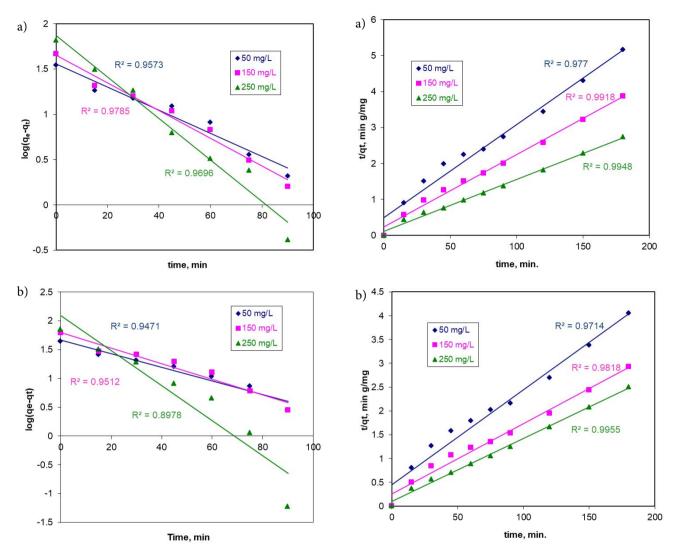


Figure 7. The pseudo-first order kinetics of arsenic (V) adsorption on mustard husk (a) and soy bran (b).

 $\label{eq:Figure 8.} \textbf{Figure 8.} \ \text{The pseudo-second order kinetics of arsenic (V) adsorption on mustard husk (a) and soy bran (b).}$

Table 2. Kinetic parameters for the adsorption of arsenic on mustard husk and soy bran.

	Initial concentration, mg/L									
Model	5	50	1:	50	250					
	Mustard husk	Soy bran	Mustard husk	Soy bran	Mustard husk	Soy bran				
Pseudo-first order										
$q_{e, exp} (mg g^{-1})$	34.86	44.39	46.52	61.43	65.79	71.94				
q _{e, calc} (mg g ⁻¹)	35.70	46.08	44.66	62.23	73.63	122.71				
k ₁ (min ⁻¹)	$2.92 \cdot 10^{-2}$	$2.7\cdot 10^{-2}$	$3.52 \cdot 10^{-2}$	$3.1 \cdot 10^{-2}$	$5.25 \cdot 10^{-2}$	$7.0 \cdot 10^{-2}$				
R^2	0.957	0.947	0.979	0.951	0.969	0.898				
Pseudo-second order										
$q_{e,\;exp}\;(mg\;g^{-1})$	34.86	44.39	46.52	61.43	65.79	71.94				
$q_{e, calc} (mg g^{-1})$	38.76	50.0	49.75	67.56	69.44	75.75				
$k_2(g mg^{-1} min^{-1})$	$1.35 \cdot 10^{-3}$	$8.88\cdot10^{-4}$	$1.71\cdot 10^{-3}$	$8.6\cdot 10^{-4}$	$1.78\cdot 10^{-3}$	$1.77 \cdot 10^{-3}$				
R^2	0.977	0.971	0.992	0.918	0.995	0.995				

An intra-particle diffusion model was used to predict the rate controlling step but in this case a non-linear relationship has been obtained. The pseudo-first-order and pseudo-second-order rate constants determined are listed in Table 2 along with the corresponding correlation coefficients. From these results it can be seen that the values of correlation coefficient decreases from pseudo second-order to pseudo first-order.

3. 8. Adsorption Isotherms

It is well known that the adsorption isotherms express the interaction between the adsorbent and adsorbate in the adsorption processes. In order to study the adsorption of arsenic ions on the two sorbents, Langmuir, Freundlich, Temkin and Flory-Huggins adsorption models have been used.

Langmuir isotherm characterizes a monolayer adsorption on a surface with a finite number of identical centers which are homogeneously distributed on the surface of the sorbent. In our study a linearized Langmuir isotherm form (Eq. 9) has been used:⁴⁴

$$\frac{C_e}{q_e} = \frac{1}{K_L \cdot q_m} + \frac{C_e}{q_m} \tag{9}$$

where: q_e represents the amount of adsorbed arsenic per sorbent unit (mg g⁻¹); C_e is arsenic ion concentration at equilibrium (mg L⁻¹); q_m is a parameter that express the maximum adsorption capacity (mg g⁻¹) corresponding to monolayer coverage; K_L is constantly referring to the adsorption energy (g L⁻¹).

 K_L and q_m parameters values were calculated from the intercept and the slope of the plot C_e/q_e vs. C_e (Figure 9).

An important characteristic of Langmuir isotherms can be expressed by the dimensionless constant (Eq.10) called equilibrium parameter or separation factor.

$$R_{L} = \frac{1}{1 + K_{T}C_{0}} \tag{10}$$

where: K_L is the Langmuir constant, C_0 is the initial concentration of As(V) ions (mg L^{-1}). For a favorable adsorption process R_L value must be between 0 and 1. In our study R_L obtained values were less than one (Table 3) which indicates that the arsenic(V) adsorption process was favorable.

The Freundlich isotherm is based on the multilayer adsorption that means a heterogeneous surface of the sorbent and a non-uniform distribution of heat of adsorption 45

A logarithmic form of this model (Eq. 11) was applied in our study:

$$\log q_{e} = \log K_{F} + \frac{1}{n} \log C_{e} \tag{11}$$

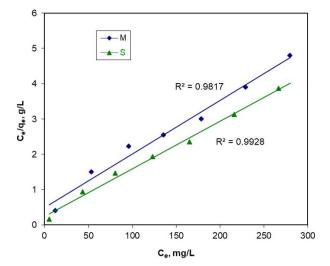


Figure 9. Langmuir isotherms for the arsenic(V) adsorption on mustard husk and soy bran.

In the above equation, q_e and C_e have the same meaning as in Eq (9); K_F ($mg^{(1-1/n)}L^{1/n}g^{-1/n}$) and n are Freundlich constants that indicate the relative adsorption capacity of the sorbent, and the adsorption intensity, respectively.

The slope and intercept of Freundlich model (Figure 10) have been used to calculate K_F and factor n. A value for 1/n less than 1 indicates a normal isotherm while 1/n > 1 suggests a cooperative adsorption. In the case of arsenic adsorption on both mustard husk and soy bran 1/n values are 0.233 and 0.179, respectively, indicating a normal isotherm adsorption.

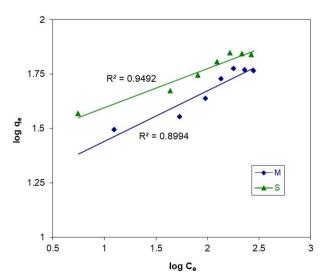


Figure 10. Freundlich isotherms for the arsenic (V) adosrption on mustard husk and soy bran.

The third adsorption isotherm model used in the present work was the Temkin model. In this case, the main assumption is that the heat of adsorption decreases linearly with coverage due to sorbent-sorbate interactions.⁴⁶ The

linear Temkin isotherm equation (Eq. 12) used in our study was:

$$q_e = B \ln A + B \ln C_e \tag{12}$$

where: A is the equilibrium constant (L g^{-1}) corresponding to the maximum binding energy and constant B (J mol^{-1}) is correlated to the heat of adsorption as follows:

$$B = RT/b_{T}$$
 (13)

where: b_T is the Temkin isotherm energy constant (J mol⁻¹) and R is the universal gas constant (8.3146 J mol⁻¹ K⁻¹). The Temkin isotherm plots for both sorbents are presented in Figure 11 and the isotherm parameters extracted are listed in Table 3.

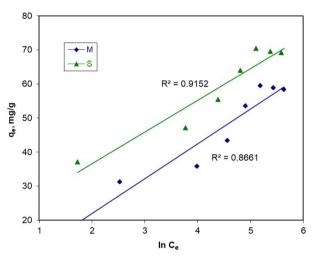


Figure 11. Temkin isotherms for the adsorption of arsenic (V) on mustard husk and soy bran.

For a most comprehensive characterization of the arsenic (V) adsorption process was used the fourth adsorption model, Flory-Huggins, in order to calculate the surface coverage of sorbent by sorbate.⁴⁷

$$\log \frac{\theta}{C_0} = \log K_{FH} + n \log(1 - \theta)$$
 (14)

where θ represents surface coverage and was calculated by Eq. (5), K_{FH} is equilibrium constant of the adsorption pro-

cess. The parameters of equation (14) were calculated from the slope and intercept of the plot $\log \theta/C_0$ *vs.* $\log (1-\theta)$ *that is depicted in Figure 12 and* are presented in Table 3.

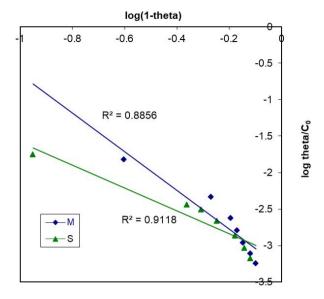


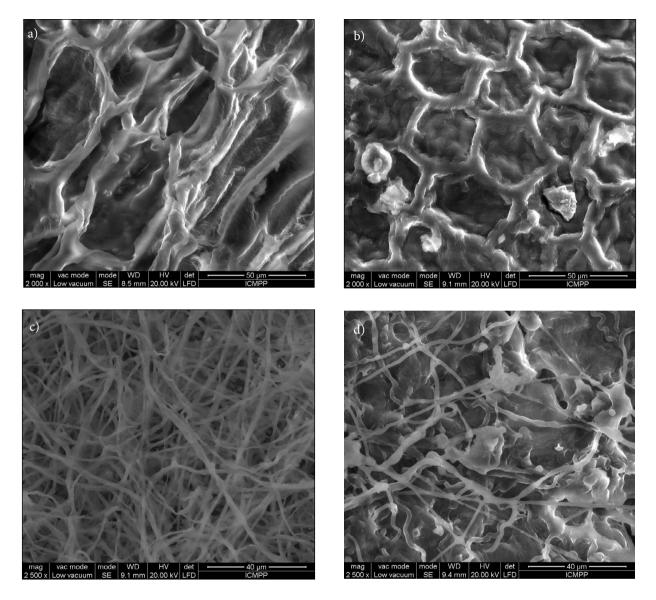
Figure 12. Flory-Huggins isotherms for the arsenic adsorption on mustard husk and soy bran.

Considering all extracted parameters for all four adsorption isotherm models (see Table 3) it can be concluded that for the arsenic (V) adsorption on the mustard husk and soy bran the best fit shows the Langmuir isotherm model. In addition, between the two analyzed materials, in terms of adsorption capacity the best candidate seems to be soy bran than of the mustard husk for arsenic (V). The efficiency of the two studied sorbents, soy bran and mustard husk, on the arsenic (V) was highlighted by a comparison with the results from the literature for other sorbents (Table 4). As can be observed the adsorption capacity of the investigated sorbents for the arsenic (V) is higher compared with some other sorbents and its low cost and abundance make it as possible materials for the use in residual waters decontamination.

The fact that in the sorption stage there are a series of processes that can affect the morphology of the adsorbent materials is pointed out by the images obtained by using a Electronic Scanning Microscope, SEM Quanta 250. Images presents the morphology of sorbens samples (Figure 13)

Table 3. Parameters for the adsorption models.

Sorbent	bent Langmuir				Freundlich		Flo	Flory-Huggins			Temkin		
	$\begin{array}{c} q_{m,} \\ (mg~g^{-1}) \end{array}$	K_L (L g^{-1})	R ²	R_{L}	K_{F}	n	R ²	K_{FH}	n	R ²	A	\mathbf{b}_{T}	R ²
Mustard husk	65.79	0.032	0.982	0.111	16.15	4.29	0.899	$1.99\cdot 10^3$	1.565	0.886	1.158	242.21	0.866
Soy bran	74.07	0.058	0.993	0.065	26.09	5.56	0.949	$1.29\cdot 10^3$	2.647	0.911	0.648	265.57	0.915



 $\textbf{Figure 13.} \ \textbf{SEM images of the mustard husk and soy bran before (a, c) and after (b, d) \ adsorption \ experiments.$

Table 4. Comparison of maximum adsorption capacity of different sorbents towards arsenic (V).

Sorbent	q _m (mg g ⁻¹)	Reference		
Rice polish	0.15	48		
Rice husk	0.225	25		
Coconut shell carbon	2.40	49		
Pine leaves	3.27	24		
Tea fungal biomass	4.95	48		
Polymeric alginate beads	8.33	50		
Coconut coir pith	13.75	51		
Withania frutescens	16.88	52		
Calami rhizoma	22.04	52		
Orange juice residue	67.43	53		
Mustard husk	65.79	This work		
Soy bran	74.07	This work		

before and after adsorption processes with enlarge X2500, scale 40 $\mu m.$

3. 9. Desorption Results

Once the sorbent is used, it needs to be regenerated. Desorption processes are important from two points of view: first, to recover metal ion and its subsequent use in industrial and secondly, in the regeneration of sorbent for new use processes.

The amount of As released from the sorbent was determined by HG-AAS and the percentage of arsenic desorbed was calculated with equation Eq. 15:

desorbed ion % =
$$\frac{amount_{des}}{amount_{ads}} \cdot 100$$
 (15)

where: amount $_{\rm des}$ is the amount of desorbed arsenic and amount $_{\rm ads}$ is the amount of arsenic adsorbed by the sorbent. The results of desorption experiments reveal that the best regeneration eluent may be aqueous solution of NaOH 0.01 M, 87.95% for mustard husk and 90.67% for soy bran, respectively.

4. Conclusions

The adsorption of arsenic (V) ions on mustard husk and soy bran was studied as a function of contact time, initial arsenic ion concentration, pH, sorbent mass and temperature, the conclusion being that the sorption capacity of the soy bran was higher than that of mustard husk.

The thermodynamic parameters indicate that adsorption of arsenic (V) ions on mustard husk and soy bran is a spontaneous ($\Delta G^{\circ} < 0$) and endothermic ($\Delta H^{\circ} > 0$) process.

This study indicates that arsenic (V) adsorption is better described by Langmuir isotherm model and the kinetic of the process obeys the pseudo second-order model.

The results obtained in desorption studies showed that, in order to recover arsenic (V) ions a 0.01 M NaOH solution may be used.

This study reveals the potential of using mustard husk and soy bran as excellent low-cost adsorbent for the removal of arsenic (V) from aqueous solutions.

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Povzetek

V zadnjem času je velika pozornost namenjena uporabi cenovno ugodnih adsorbentov za čiščenje kontaminiranih voda. S namenom smo preverili potencial sojinih lupin in gorčičnih luščin za odstranjevanje arzena (V) iz odpadnih voda. Preučili smo vpliv procesnih parametrov kot so kontaktni čas, pH vrednost, začetna koncentracija arzena, količina adsorbenta in temperatura na odstranjevanje arzena (V). Termodinamski parametri so pokazali, da je proces pod preučevanimi pogoji spontan in endotermen. Separacijski faktor je bil manjši kot ena kar kaže, da je adsorpcija ugodna. Adsorpcijsko ravnotežje lahko dobro opišemo z Langmuirjevo izotermo z maksimalno kapaciteto vezave arzenovih (V) ionov na sojine lupine 74.07 mg g $^{-1}$ in na gorčične luščine 65.79 mg g $^{-1}$. Kinetiko lahko opišemo z reakcijo psevdo-prvega reda.