



SORPTION OF CADMIUM FROM WATER USING NEUTRALIZED RED MUD AND ACTIVATED NEUTRALIZED RED MUD

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ABSTRACT

In this study seawater-neutralized red mud (Bauxsol) and Bauxsol which is acid treated (aBauxsol) and acid-heat treated (AB) were used as adsorbents for removing of Cd (II) from water. Batch sorption experiments were carried out to investigate the sorption of Cd (II) to the sorbents with particular focus on sorption kinetics, sorption capacity and isotherms. The sorption equilibrium data for present sorbent/sorbate system were tested by both Langmuir and Freundlich models. The values of ΔG° for Cd (II) ion indicate that the adsorption process is spontaneous. Pseudo-second order kinetic model provided a perfect fit for the kinetic data of Cd (II) sorption. Based on the sorption and kinetic information obtained for Cd (II) removal by these sorbents, it may be concluded that AB are the most effective sorbent for Cd (II).

Keywords: Cd (II), sorption, isotherm, Bauxsol, aBauxsol, AB.

1. INTRODUCTION

Over the past few decades the use of heavy metals significantly increases, resulting in an increased metal pollution of the aquatic ecosystems. The heavy metals are of special concern because they are not biodegradable. The important toxic metal is cadmium. The main anthropogenic sources of cadmium are numerous industrial processes: production of aluminium, plastic, cadmium-nickel batteries, fertilizers, pesticides, pigments and dyes, etc. According to The World Health Organization's recommendation Cd (II) limit in drinking water is 0.005 mg/L [1].

The increase in Cd concentration because of rapid industrial development requires continuous development of the methods for its removal from wastewater: precipitation [2, 3], ion exchange [4-7], extraction [8-10], membrane separations [11, 12]. These traditional methods have a number of disadvantages: low efficiency especially at low concentrations of metal, high capital costs, sensitive working conditions and generation of toxic sludge that require further safe disposal [13]. On the other hand, sorption is an attractive, alternative technique for the removal of heavy metals from wastewaters. It has many advantages: cheap and easily available sorbents, the use of industrial and biological waste, reuse of sorbent after the regeneration, the possibility of ion removal over a wide pH range and concentrations [13-16]. An example of such a cheap and easily available sorbent, industrial waste, is a red mud, by-product of alumina production from bauxite, which is deposited in large quantities. It represents an environmental problem, and alternative methods must be developed for its use. The literature data indicate that the red mud and products of its treatment can be successfully used to remove heavy metals from wastewaters [17-20]. Seawater-neutralized red mud (Bauxsol) and Bauxol which is acid treated (aBauxsol) and acid-heat treated (AB) showed good characteristics for the sorption of arsenic, lead and copper from aqueous solutions [21-24].

The aim of this paper was to investigate the sorption potential of Bauxsol, aBauxsol and AB for the

removal of cadmium from aqueous solutions with particular focus on sorption kinetics, sorption capacity and isotherms.

2. EXPERIMENTAL

2.1. Apparatus

Cadmium was analyzed using flame atomic absorption spectrophotometry (FAAS) (Perkin Elmer AAnalyst 300). A laboratory pH meter (Metrohm 827) was used for pH measurements. The BET specific surface areas were determined by the standard technique of nitrogen adsorption using a Sorptomatic 1990 Thermo Finning instrument.

2.2. Preparation of sorbents

In this study the red mud obtained from the Aluminium Factory Podgorica was used. Its modification resulted in formation of Bauxsol, aBauxsol and AB. Bauxsol is seawater-neutralized red mud. It has the ability to neutralize highly acidic wastewaters and transform heavy metals from wastewaters into stable mineral forms. It is hardly soluble in the water, so it is possible to isolate easily the reacted Bauxsol, if necessary [25]. Bauxsol for experiments was obtained by mixing 2 kg of red mud with 1 dm³ of sea water for one hour. It was mixed to reach pH values from 8.2 to 8.8, and then filtered and dried. Before use Bauxsol was sifted through the filter with the pore size of 0.2 mm. In order to obtain aBauxsol, Bauxsol powder was treated with 20% HCl for 20 minutes. The obtained deposit was filtered and washed three times with deionized water to remove acid and dissolved compounds. It was then dried at the temperature of 40°C and sifted through a sieve with the pore size of 0.2 mm. The obtained Bauxsol modification was used in the experiments without further treatment. The treatment with hydrochloric acid was used to remove the sodium compounds [21, 26], resulting in the increased sorption capacity of Bauxsol [27]. AB was prepared by the treatment of Bauxsol powder with 20% HCl, for 20 minutes, which was then deposited with



ammonia at the pH value of 8. The deposit was filtered and washed three times with deionized water. Afterwards, the deposit was dried for 12 h at the temperature of 110 °C and then calcinated for 2 h in air at the temperature of 500 °C. The deposit was then sifted through a sieve with the pore size of 0.2 mm and kept in a desiccator until used for the experiment. Combining acid and thermal treatment of Bauxsol the content of Fe- and Al- oxide increases, as well as the capacity of ion exchange [22], which altogether can improve the sorption characteristics of AB Bauxsol.

The chemical analysis of the sorbent was done using standard methods [28, 29].

2.3. Batch experiments

The cadmium stock solution (0.1 mol/dm³) was obtained by dissolving 26.649 g of Cd(CH₃COO)₂ · 2H₂O in 1 dm³ 5% HNO₃. The dilution of the base solution with distilled water resulted in a number of solutions, with the concentration within the range from 0.05 mmol/dm³ (5.62 mg/dm³) to 1 mmol/dm³ (112.4 mg/dm³).

In order to estimate the efficiency of cadmium removal from the solution using Bauxsol, aBauxsol and AB, numerous experiments were done. Before the contact with the sorbent, the pH of the tested solution was adjusted to 5.5. The volume of 50 ml of the solution of the metal with the appropriate concentration was treated during the

periods of 5, 10, 15, 30, 60, 90 and 120 minutes with 0.2 g of sorbent, where the intense mixing on a magnetic stirrer, and then filtering through a microfilter were performed. After filtration, the concentrations of metals in the filtrate were determined using AAS technique. The amount of cadmium adsorbed (q_t) in mmol/g at time t was calculated using the following equation:

$$q_t = \frac{(C_0 - C_t)V}{m} \quad (1)$$

where C₀ and C_t are the Cd (II) concentrations in mmol/dm³ initially and at a given time t, respectively, V is the volume of Cd (II) in ml, and m is the weight of sorbent in g.

3. RESULTS AND DISCUSSIONS

3.1. Sorbent properties

The chemical compositions of the major components in red mud, Bauxsol and activated Bauxsol (aBauxsol and AB) are given in Table-1.

The specific surface area of Bauxsol, aBauxsol, and AB samples, determined using the BET-N₂ method [30], were 32, 43, and 58 m² g⁻¹, respectively.

Table-1. Chemical composition of the major components in red mud and its modifications.

Component	Red mud	Bauxsol	aBauxsol	AB
	% (w/w)			
Fe ₂ O ₃	41.52	42.50	42.86	44.58
Al ₂ O ₃	17.51	11.31	18.10	10.67
SiO ₂	12.28	10.90	11.90	11.55
TiO ₂	10.50	7.57	6.55	9.45
CaO	1.56	4.35	1.80	0.90
Na ₂ O	7.20	7.80	1.10	0.45

3.2. Effect of contact time and concentration

On the basis of Figure-1, which shows the dependence of the sorbed amount of Cd (II) per mass unit of sorbent on contact time at different initial concentrations of the solution, it can be seen that the curve shape does not depend on the initial solution concentration. Each curve consists of two parts, one of which corresponds to the fast phase, and the other to the slow phase of the process, indicating the heterogeneity of the sorption processes. The fast phase at the beginning of the sorption process is influenced by the high driving force for mass transfer due to large differences in concentrations of metals in the solution and on the sorbent surface, as well as to a large number of free active sites on the sorbent

surface. Over time, the driving force for mass transfer is reduced, which results in slowing down the sorption process in the second phase [31]. The sorbed amount of metals per mass unit of the sorbent increases until the equilibrium is established.

The experimental results show that the sorption level of Cd (II) in all three sorbents increases significantly in the initial phases of the process and becomes slower at later phases up to saturation (Figure-1). The time required for equilibration depends on the initial solution concentration and ranges from 15 min to 60 min (Table-2). Moreover, the percentage of cadmium removal depends on the initial concentration of the solution.

**Table-2.** Effect of contact time and initial Cd (II) concentration on percentage of cadmium removal.

Sorbent	Initial Cd (II) concentration mmol/dm ³	q _t , mmol/g	Cadmium removal, %	Time
Bauxsol	0.05	0.008	64	15
	0.1	0.0155	62	15
	0.5	0.065	52	60
	1	0.105	42	60
aBauxsol	0.05	0.007	86	15
	0.1	0.020	81	15
	0.5	0.081	65	60
	1	0.154	57.6	60
AB	0.05	0.0113	91	15
	0.1	0.0225	90	15
	0.5	0.106	84.8	30
	1	0.172	68.8	60

The quick sorption of Cd (II) suggests that chemical sorption rather than physical sorption contributes to Cd (II) sorption on these minerals surfaces [32].

The percentage of removed cadmium is determined from the ratio of the concentration of cadmium present in the solution and in particulate phase using the equation:

$$\% \text{ of cadmium sorbed} = [(C_0 - C_e) / C_0] \times 100 \quad (2)$$

where C_0 and C_e are the initial and equilibrium cadmium concentrations, respectively.

The percentage of sorption decreases with the increase of the initial concentration [33, 34]. For example, the percentage of sorption on Bauxsol decreases from 64% to 42% with the increase of the concentration from 0.05 mmol/dm³ to 1 mmol/dm³. Similar situation happens with aBauxsol, where the removal percentage decreases from 86% to 57.6% with the change of concentration within the same range as on Bauxsol. This statement is in accordance with the lack of sufficient number of active sites on the surface of the sorbent for ion binding at higher initial concentrations. The Figure-1 shows that the removal percentage increases in the following order Bauxsol - aBauxsol - AB.

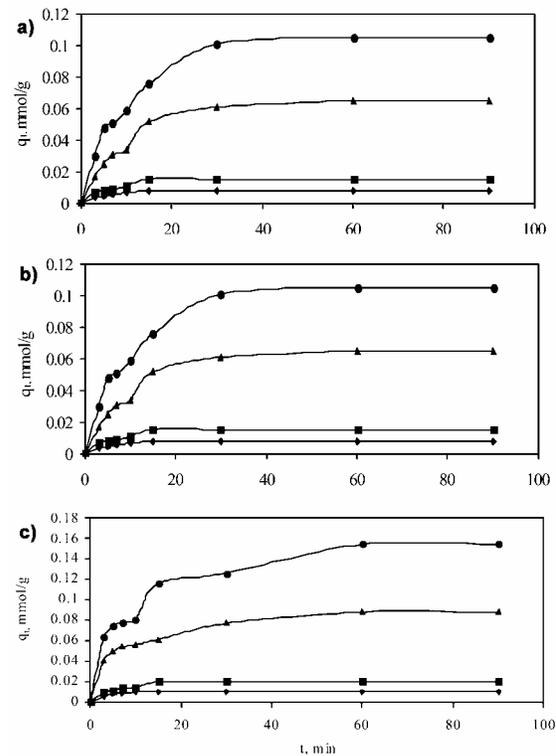


Figure-1. Sorbed amount of Cd (II) in function of time and concentration on: a) Bauxsol, b) aBauxsol, c) AB. Initial concentrations of the solution (mmol/dm³): (◆) 0.05, (■) 0.10, (▲) 0.50, (●) 1.00.

3.3. Sorption kinetics

In order to explain the kinetics of Cd (II) sorption on Bauxsol, aBauxsol and AB the kinetic models of pseudo first and pseudo second order were used. The



linearized form of the pseudo first - order equation is given as:

$$\ln(q_e - q_t) = \ln q_e - k_1 t \quad (3)$$

where: q_e and q_t (mmol/g) are the amount of metal ions sorbed per mass unit of the sorbent at equilibrium and time t , respectively. The dependence $\ln(q_e - q_t) = f(t)$ is a straight line (Figure-2) whose slope and intercept values were used to determine the values of q_e and sorption rate constant k_1 (Tables 3, 4 and 5).

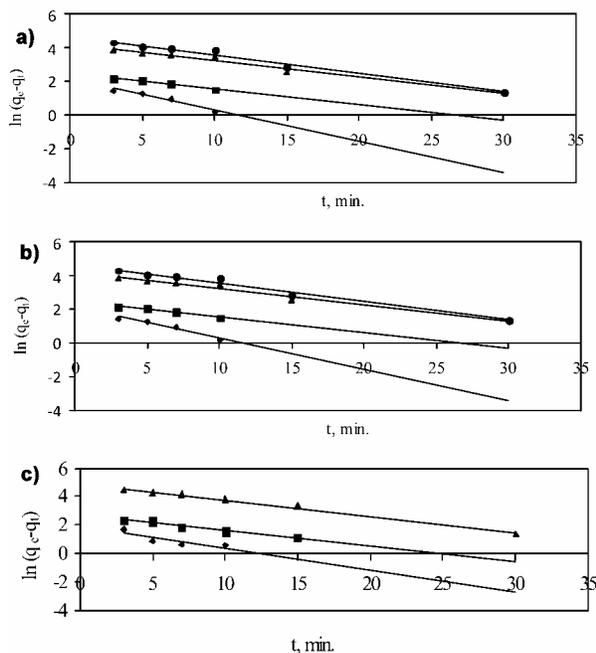


Figure-2. Pseudo first order model for sorption of Cd (II) ions on: a) Bauxsol, b) aBauxsol, c) AB. The initial concentrations of the solution (mmol/dm³): (◆) 0.05, (■) 0.10, (▲) 0.50, (●) 1.00.

The kinetic model of pseudo second order is presented by the equation:

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{t}{q_e} \quad (4)$$

where: k_2 (g/mmol min) = reaction rate constant of pseudo second order; q_t and q_e (mmol/g) = the amount of the sorbed metal ions per mass unit of sorbent at time t and equilibrium, respectively.

The diagrams $t/q_t = f(t)$ for the model of pseudo second order for the sorption of Cd (II) in all three sorbent are shown in Figure-3.

The corresponding parameters obtained using these two models for the sorption of Cd (II) on Bauxsol, aBauxsol and AB are given in Tables 3-5.

On the basis of the value R^2 (Table 3-5) for these two models it can be concluded that the model of pseudo second order describes better the sorption processes for all the investigated concentrations and used sorbents. Good correlations of experimental data with the pseudo-second order kinetic model have been reported for the sorption of Cd (II) on bentonite and zeolite and montmorillonite [35, 36].

For the sorption on Bauxsol, the values of equilibrium capacity predicted by this model are as follows: 0.029 mmol/g, 0.045 mmol/g, 0.200 mmol/g and 0.333 mmol/g, while the corresponding values obtained by the experiment are: 0.023 mmol/g, 0.043 mmol/g, 0.126 mmol/g and 0.225 mmol/g. On aBauxsol, mathematically derived values of q_e are: 0.030 mmol/g, 0.050 mmol/g, 0.200 mmol/g and 0.330 mmol/g, and the experimentally obtained are as follows: 0.010 mmol/g, 0.048 mmol/g, 0.157 mmol/g and 0.339 mmol/g. On AB the mathematical values of q_e are: 0.050 mmol/g, 0.250 mmol/g and 1.000 mmol/g, while the corresponding experimental values are: 0.049 mmol/g, 0.203 mmol/g and 0.656 mmol/g.

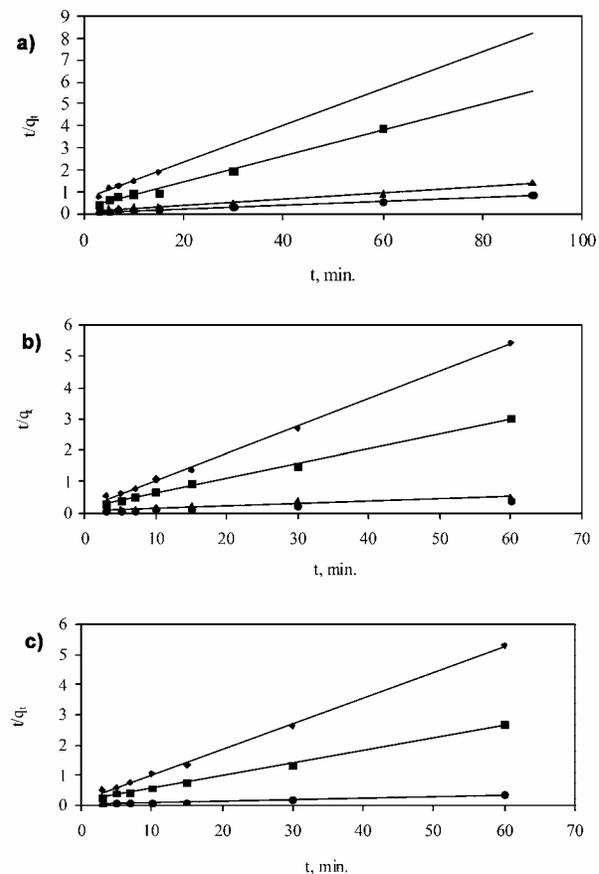


Figure-3. Model of pseudo second order for the sorption of Cd (II) ions on: a) Bauxsol, b) aBauxsol, c) AB. The initial concentration of the solution (mmol/dm³): (◆) 0.05, (■) 0.10, (▲) 0.50, (●) 1.00.

**Table-3.** Kinetic parameters for the sorption of Cd(II) ions on Bauxsol.

Kinetic model	Parameter	Solution concentration (mmol/dm ³)			
		0.05	0.1	0.5	1.0
Pseudo first order	$K_L(\text{min}^{-1})$	0.185	0.09	0.094	0.110
	q_e (mmol/g)	0.083	0.012	0.065	0.11
	R^2	0.952	0.972	0.982	0.984
Pseudo second order	K_2 (g/mmolmin)	15.8	13.16	1.41	0.93
	q_e (mmol/g)	0.01	0.017	0.077	0.125
	R^2	0.962	0.992	0.995	0.996

Table-4. Kinetic parameters for the sorption of Cd (II) ions on aBauxsol.

Kinetic model	Parameter	Solution concentration (mmol/dm ³)			
		0.05	0.1	0.5	1.0
Pseudo first order	$K_L(\text{min}^{-1})$	0.167	0.039	0.020	-
	q_e (mmol/g)	0.008	0.009	0.08	-
	R^2	0.879	0.812	0.978	-
Pseudo second order	K_2 (g/mmolmin)	42.7	13.88	0.549	0.55
	q_e (mmol/g)	0.01	0.02	0.14	0.2
	R^2	0.998	0.997	0.923	0.987

Table-5. Kinetic parameters for the sorption of Cd (II) ions on AB.

Kinetic model	Parameter	Solution concentration (mmol/dm ³)		
		0.05	0.1	1.0
Pseudo first order	$K_L(\text{min}^{-1})$	0.152	0.107	0.115
	q_e (mmol/g)	0.006	0.014	0.135
	R^2	0.773	0.970	0.993
Pseudo second order	K_2 (g/mmolmin)	65.79	11.85	1.14
	q_e (mmol/g)	0.010	0.025	0.200
	R^2	0.998	0.998	0.999

This confirms the good agreement between experimental and theoretical results for all three sorbents, especially at lower concentrations of sorbate. It is also evident that with increasing initial solution concentrations the values of the constants K_2 grow, which is in accordance with literature data [37].

values of equilibrium concentration. As the concentration increases the slope decreases and the curves move to the area of plateau. The sorbed amount of metal ion, which refers to the curve plateau, represents the maximum sorption capacity under the given experimental conditions (q_m).

3.4. Sorption isotherms

When the sorbent is in contact with fluid the sorbates are tied, and after certain time the equilibrium is established. Knowing the equilibrium is important, because it defines the sorption capacity of the sorbent under the given experimental conditions. Sorption isotherms obtained in studied systems are shown in Figure-4.

The presented isotherms belong to L-type isotherms and they have a significantly higher slope at lower initial concentrations, which correspond to the lower

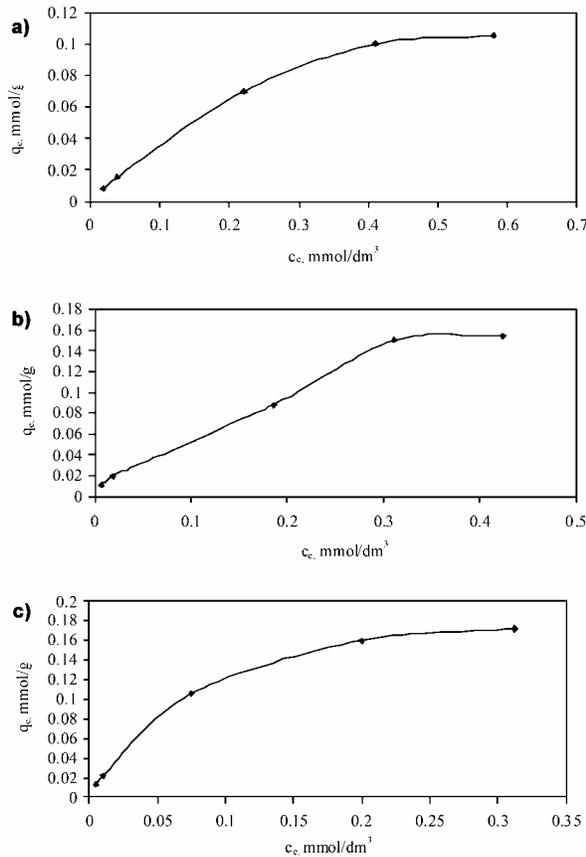


Figure-4. Sorption isotherms of Cd(II) ions on: a) Bauxsol, b) aBauxsol, c) AB.

From the Figure-4 it is evident that the maximum sorption capacities are 0.105, 0.154 and 0.172 mmol/g for Bauxsol, aBauxsol and AB, respectively. This fact suggests that AB has the best sorption characteristics under the given experimental conditions.

The sorption data were analyzed by different sorption isotherms, namely Langmuir and Freundlich. The linearized form of Langmuir isotherm is given by the equation:

$$\frac{C_e}{q_e} = \frac{1}{q_m K_L} + \frac{C_e}{q_m} \quad (5)$$

C_e (mmol/dm³) = equilibrium concentration of the metal in the solution; q_e (mmol/g) = amount of metal ion sorbed at equilibrium; K_L and q_m are the Langmuir constants related to the sorption capacity and sorption energy, respectively. Precisely, the maximum sorption capacity (q_m) represents monolayer coverage of sorbate over the sorbent, while K_L is the sorption enthalpy. The values of q_m and K_L were determined on the basis of slope and intercept of the diagram $c_e/q_e = f(c_e)$ (Figure-5).

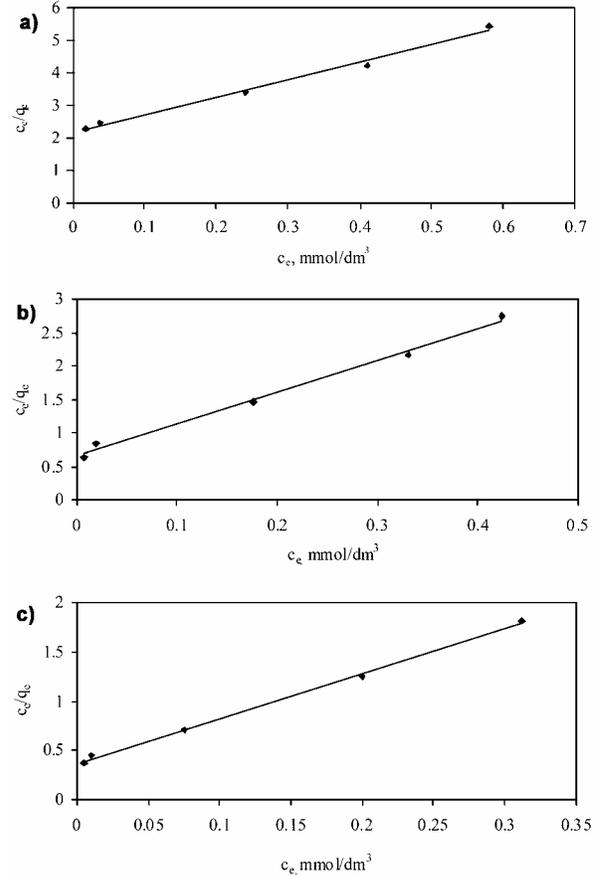


Figure-5. Langmuir sorption isotherm of Cd(II) ion on: a) Bauxsol, b) aBauxsol, c) AB.

On the basis of the values of K_L , the separation factor R_L and Gibbs energy can be calculated:

$$R_L = \frac{1}{1 + K_L C_0} \quad (6)$$

where: C_0 = initial concentration of metals in the solution.

The Gibbs energy is an important parameter because it indicates the possibility of realization of sorption process and it can be presented by the following equation:

$$\Delta G = -RT \ln K_L \quad (7)$$

The factor R_L indicates the shape of isotherm and nature of sorption process ($R_L > 1$ - non-favoured; $R_L = 1$ - linear, $0 < R_L < 1$ - favoured; $R_L = 0$ - irreversible). The parameters of Langmuir isotherm along with the values of R^2 , R_L are shown in Table-6.

**Table-6.** Parameters of langmuir and freundlich isotherm for the sorption of Cd (II) ions on different sorbents.

Isotherm model	Parameter	Bauxsol	aBauxsol	AB Bauxsol
Langmuir	K_L (dm ³ /mmol)	2.58	7.56	12.42
	q_m (mmol/g)	0.18	0.20	0.22
	R_L	0.13-0.88	0.05-0.73	0.15-0.64
	R^2	0.991	0.992	0.998
Freundlich	K_f (mmol/g)	0.170	0.326	0.523
	n	1.31	1.46	1.49
	R^2	0.991	0.989	0.990

The table shows that the sorption capacities increase in the following order Bauxsol - aBauxsol - AB and their values are 0.18 mmol/g, 0.20 mmol/g and 0.22 mmol/g. These values are close to the experimentally determined values of maximum sorption capacity, which justifies the applicability of Langmuir isotherm to describe the equilibrium of the examined sorption processes [38]. The correlation coefficient R^2 also indicates a good agreement between the mathematical and experimental results. Its highest value is for AB, $R^2 = 0.998$. The applicability of Langmuir isotherm on the investigated systems indicates the formation of sorbate monolayer of on the surface of sorbent. R_L values are between 0 and 1 and indicate that the sorption process is favoured, as confirmed by the convex form of sorption isotherms.

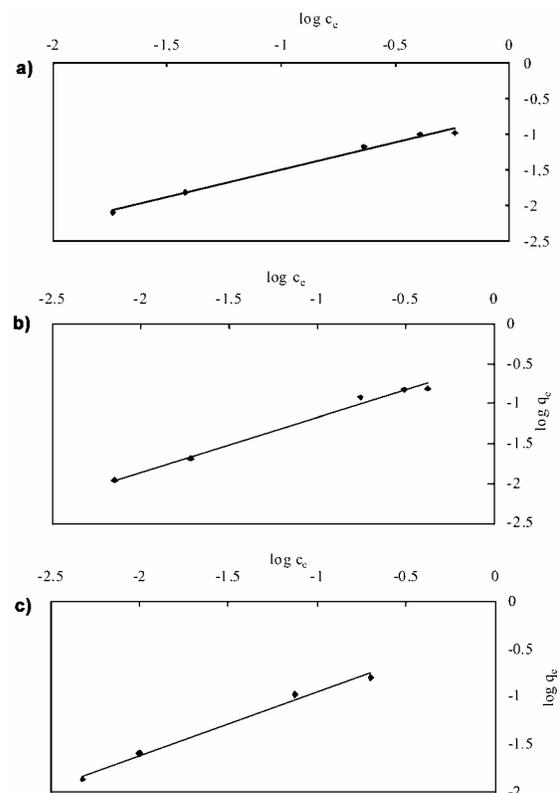
The negative values for Gibbs energy ($\Delta G = -2.35$ kJ/mol for Bauxsol, $\Delta G = -5.011$ kJ/mol for aBauxsol and $\Delta G = -6.24$ kJ/mol for AB) indicate that the process takes place spontaneously at room temperature. The values of ΔG , favoured sorption, as well as the spontaneity of the process are in accordance with literature data [39, 34, 40].

The obtained experimental results are also analyzed using Freundlich isotherm model. Freundlich isotherm is the earliest known equation describing the sorption process. This fairly satisfactory empirical isotherm can be used for non - ideal sorption that involves heterogeneous sorption.

The linear form of Freundlich isotherm is presented by the following equation:

$$\log q_e = \frac{1}{n} \log c_e + \log K_f \quad (8)$$

where: K_f and $1/n$ are Freundlich constants related to the sorption capacity and sorption intensity, respectively. A plot of $\log q_e$ vs. $\log c_e$ (Figure-6) gives the values of K_f and $1/n$, which are determined from slope and intercept of linear plots. The linear plots show that the sorption of Cd(II) on Bauxsol, aBauxsol and AB followed the Freundlich isotherm model. The calculated values of K_f and $1/n$ are given in Table-6. As the value of $1/n$ it indicates favourable sorption of Cd(II) ions. The sorption capacities of K_f increase in the following order Bauxsol - aBauxsol - AB, which is in accordance with previously mentioned statements.

**Figure-6.** Freundlich sorption isotherms of Cd (II) ions on: a) Bauxsol, b) aBauxsol, c) AB.

On the basis of the factor R^2 (Table-6) it can be concluded that the Langmuir isotherm gives a better description of the sorption of Cd (II) ions in all three sorbents with respect to Freundlich isotherm, which is in accordance with literature data.

The value of K_f shows that AB has the highest affinity for the sorption of cadmium, which supports the above mentioned conclusions about the highest percentage of removal of cadmium with AB, as well as its highest sorption capacity.

Comparison of adsorption capacities of modified and unmodified red mud used for Cd (II) removal from water (including the results of this study) are shown in Table-7.



Table-7. Adsorption capacity of different sorbents on the basis of red mud for the removal of Cd (II) ions from water.

Sorbent	q_m (mg/g)	Reference
Red mud	13.03	39
Red bauxite	38.77	41
Granular red mud	38.2	40
red mud	10.57	42
Red mud	68	43
red mud and fly ash	46.9-66.8	44
Bauxsol	20.32	This paper
aBauxsol	22.48	This paper
AB	24.73	This paper

3.5. Mechanism of mass transfer

3.5.1. Diffusion in the fluid film

The kinetics of the sorption process in the investigated systems in function of initial concentration of Cd (II) in the solution served for determination of the mass transfer coefficient using the Mathews - Weber model:

$$\ln \frac{c_t}{c_0} = -k_f t \quad (9)$$

which defined the diffusion in fluid film around the particles. From the slope of the obtained rectilinear dependences $\ln c_t/c_0 = f(t)$ (Figure-7) the volume mass transfer coefficients were determined and presented in Table-8.

The data in Table-8 show that the increase of the initial concentration causes the decrease in the mass transfer coefficient values. It can be explained by the mechanism of binding of Cd (II) ions to the sorbent surface, which takes place by ion exchange. The resistance to the diffusion of Cd (II) ions is provided by the interchangeable cations going from the surface of sorbent. In this way they create a concentration gradient with the opposite direction compared to the one formed by the diffusion of Cd (II) ions. The resistance increases with increasing concentrations of Cd (II) ions as the amount of discharged cations increases, causing lower values of the volume mass coefficients.

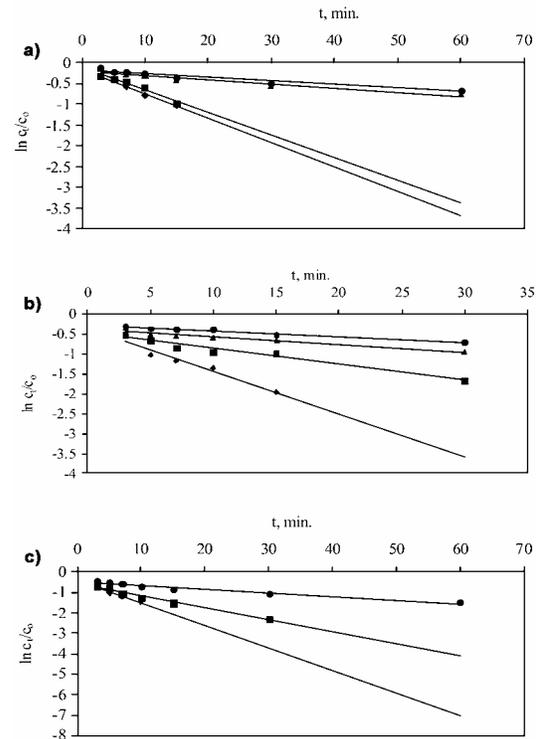


Figure-7. Fitting the experimental results of the sorption of Cd(II) ions using the linear form of M&W equation on: a) Bauxsol, b) aBauxsol, c) AB. The initial concentration of the solution (mmol/dm^3): (\blacklozenge) 0.05, (\blacksquare) 0.10, (\blacktriangle) 0.50, (\bullet) 1.00.

Table-8. Volume mass transfer coefficients through the fluid film during the sorption of Cd (II) ions on Bauxsol, aBauxsol and AB from the solution of different concentrations.

c_0 (mmol/dm^3)	$k_f a$ (1/min)		
	Bauxsol	aBauxsol	AB
0.05	0.058	0.107	0.110
0.1	0.054	0.039	0.059
0.5	0.010	0.020	-
1.0	0.008	0.014	0.018

3.5.2. Diffusion within particle

The sorption kinetics is usually controlled by different mechanisms, of which the most limiting are the diffusion mechanism, including the initial curved portion, a gradual sorption stage due to intra-particle diffusion, followed by a plateau to equilibrium where the intra-particle diffusion starts to decrease due to the low concentration in solution as well as fewer available sorptions. The most frequently used model to define the diffusion inside the particle and evaluate the degree that controls the overall sorption process is Weber - Morris model, given by the equation:



$$q_t = k_{id} \cdot t^{0.5} + C, \quad (10)$$

where:

q_t (mmol/g) = sorbed amount of sorbate per mass unit of the sorbent at a given time t , k_{id} (mmol/g min) = diffusion constant of sorbate in the sorbent particles.

The Weber - Morris model, used to present the diffusion inside the particle and define present resistance within the overall sorption process is given in Figure-8.

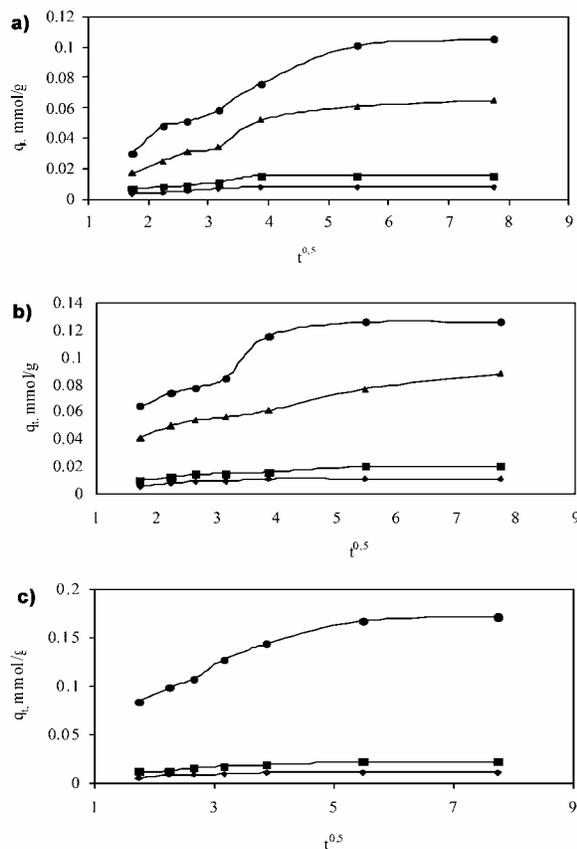


Figure-8. Weber-Morris model for the sorption of Cd (II) ions on: a) Bauxsol, b) aBauxsol, c) AB. The initial concentration of the solution (mmol/dm³): (◆) 0.05, (■) 0.10, (▲) 0.50, (●) 1.00.

The figure shows clearly that the obtained dependencies are not rectilinear and they do not pass through the origin, which indicates the presence of the diffusion through the fluid film and diffusion inside the sorbent pores [45, 46]. The curves consist of two parts: the first phase of the process, introduced by the first segment of the curve, refers to the diffusion of metal ions through the fluid film, and the second phase refers to the diffusion in the pores of the sorbent. The existence of these two phases in the sorption process of Cd (II) on synthetic Al₂O₃ was noted by Sen and Sarzali [47].

4. CONCLUSIONS

This paper shows that the red mud, waste material, can be transformed into an efficient sorbent for the removal of Cd (II) ions from wastewaters. The sorption of Cd (II) depends on the initial solution concentration and contact time. It was shown that the quantity of removed cadmium decrease with increasing initial concentration of cadmium in solution for all sorbents. The time for the establishment of equilibrium depends on the initial concentration of metal. Only 60 minutes are enough to establish equilibrium in the most concentrated solution, while in the most diluted solutions it takes less than 15 minutes. The sorption equilibrium data for the present sorbent-sorbate systems followed Langmuir isotherm model. The values of maximum sorption capacities indicate that AB has the best sorption characteristics. The negative ΔG values indicate the spontaneity of the sorption of Cd (II) at room temperature. Cadmium sorption kinetics on Bauxsol, aBauxsol and AB were very well described with the second - order rate reaction.

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