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KINETIC AND EQUILIBRIUM STUDIES OF ADSORPTION OF LEAD (II) IONS FROM AQUEOUS SOLUTION USING COIR DUST (*Cocos nucifera L.*) AND IT'S MODIFIED EXTRACT RESINS

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Metal detoxification of waste water and industrial effluents are of increasing importance to industrialization in the twenty first century. The ability of coconut (cocos nucifera L) coir dust (CD), carbohydrate toluenediisocyanate resin (CTR) and sulphonated toluenediisocyanate resin (STR) to remove Pb(II) ions from aqueous solution by ion exchange was studied. Percentage ion exchange efficiency of the resins were found to increase in the order CD(65)> CTR(52) >STR(48). The extent of removal of Pb(II) was found to be dependent of contact time, temperature and initial metal concentration. The optimum time and pH were found to be 60 mins and 7.0 respectively for the three resins.

The adsorption studied include both equilibrium adsorption isotherms and kinetics. Several isotherm models were investigated and the adsorption isotherm data were best represented by Freundlich and Flory-Huggins isotherms due to the observe high correction coefficient of 0.847, 0.944 and 0.902 for Frenudlich and 0.802, 0.963 for CD and CTR with Flory-Huggins model for the equilibrium studies.

The kinetic data were well described by the pseudo-second order kinetic model as indicate by the high value of correlation coefficient R^2 and rate constant K_2 as 0.725, 0.94 and 0.858 for CD, CTR and STR. The result indicate that CD, CTR and STR could be employed as an alternative, low-cost adsorbent for the removal of Pb(II) ions from solutions and thus decontaminating industrial effluents.

Key words: adsorption, ion exchange, heavy metals, isotherm models, industrialization.

Kinetička i ravnotežna studija adsorpcije olovo (II) iona iz vodene otopine pomoću prašine kokosa (*Cocos nucifera L.*) i modificiranog ekstrakta smole. U dvadeset prvom stoljeću raste važnost detoksikaciji metala iz otpadnih i industrijskih voda koje su nastale industrijalizacijom. Proučavana je sposobnost kokosove prašine (CD) iz kokosa (Cocos nucifera L), karboksilne toluendizocijanatne smole (CTR) i sulfonske toluendizocijanatne smole (STR) za uklanjanje Pb (II) iona iz vodene otopine ionskom izmjenom. Pronađeno je da postotak učinkovitost ionske izmjene raste u nizu CD (65)> CTR (52)> STR (48). Utvrđeno je da stupanj uklanjanja olova (II) ovisi o vremenu kontakta, temperaturi i početnoj koncentraciji metala. Optimalno vrijeme je 60 minuta, a pH 7.0 za sve tri smole. Adsorpcijska studija uključuje ravnotežne adsorpcijske izoterme i kinetiku. Istraživano je nekoliko adsorpcijskih izotermi, a ravnotežne adsorpcijske podatke najbolje opisuju Freundlichova i Flory-Huggins izoterma zbog visoke vrijednosti koeficijenta korelacije 0,847, 0,944 i 0,902 za Frenudlich i 0,802, 0,963 za CD i CTR za Flory-Huggins model.

Kinetički podaci su opisani kinetičkim modelom pseudo-drugog reda i ukazuju na visoku vrijednost koeficijenta korelacije R^2 i konstante K_2 0,725, 0,94 i 0,858 za CD, CTR i STR. Rezultat ukazuje da se CD, CTR i STR mogu koristiti kao alternativni, jeftini adsorbensi za uklanjanje Pb (II) iona iz otopine i time dekontaminirati industrijske otpadne vode.

Ključne riječi: adsorpcija, ionska izmjena, teški metali, modeli izotermi, industrijalizacija.

INTRODUCTION

The removal of heavy metals from our environment especially from aqueous solution a now shifting from the use of conventional adsorbent to the use of modified and unmodified biowaste. The presences of heavy metal in our environment in a toxic quantity possess severe life and environmental threat. In recent years, the potency of agricultural waste as low cost sorbent and their biosorption capacity has been explored [1]. The primary sources of heavy metal in the environment are anthropogenic such as industrial effluent, electroplating, metallurgical industries etc [2]. Many processes exist for the removal of heavy metals from aqueous solution such as precipitation, ion exchange, solvent extraction, reverse osmosis and adsorption [3-5].

The permissible limit of lead in drinking water is 0.05 mg/dm^3 [6]. The presence of excess lead in drinking water causes diseases such as anemia, encephalopathy and hepatitis. Lead ion has an affinity for ligands containing thiols and phosphatic groups and they inhibit the synthesis of heme, causing damage both to kidney and liver. This behaviour of lead is similar to that of calcium. However, lead can remain immobilized for years and hence, it is difficult to detect the metabolic disorders it causes [1]. The use of adsorbent such as modified groundnut husk, lignite material, bagasse and fly ash, modified sawdust and sugar beat pulp for the removal of Pb (II) from aqueous solution has been reported [7-10].

In this research, systematic laboratory investigations of the removal of Pb (II) from aqueous solutions using low cost adsorbent coconut coir dust and it's modified extract resins as adsorbent by batch adsorption techniques has been reported.

MATERIALS AND METHOD

Collection of Materials

Coconut coir dust (Cocos nucifera L.) was obtained from a local Coconut processing mill in Abak, Nigeria.

Treatment of Sample

The coconut coir dust after collection was air dried for 24 hours and then oven dried at 60 °C to constant weight. The dried coir dust was separated into different particle sizes ranging from 63-800 μm and stored in air tight lid containers. The dried coir dust was then place in 1000 cm^3 beaker and heated with water in a heating mantle to remove all coloured impurities and then the washed coir dust (CD) was air dried then oven dried for 48 hours to constant weight.

Extraction of Coconut coir Dust

The dried coir dust was extracted using soxhlet apparatus. About 2 g of the coir dust was introduce into the thimble of the soxhlet apparatus and fitted to a round bottom flask containing about 600 cm^3 acetone and heated to 75-85 °C. The top of the thimble was connected to a condenser which was then connected to a water source.

The setup was allowed to run for 1hours until all the extract in the coir has been completely removed. The round bottom flask containing the residual extract in acetone was distilled and the extract was obtained and dried in a desiccator for 48 hours and stored in an air tight container.

Modification

The extract obtained was then modified using cross linking agent to obtain highly cross linked polymeric resins having characteristic properties to enhance efficient adsorption of metal ions from solution.

The extract was modified into two resins viz, Carboxylated Toluenediiso-cyanate Resin (CTR) and Sulphonated Toluenediisocyanate Resin (STR). The car-boxylated toluene resin is obtain by agitating 1 mole of the extract with 1 mole of 4 – hydroxyl carboxylic acid and 2 moles of toluenediisocyanate (TDI) for 15 minutes then dried for 24 hours.

The sulphunated toluene resin is obtained by simultaneous agitation of 1 mole of the coir extract with 1 mole of phenol-4-sulphone acid and 2 moles of toluene diisocyanate (TDI) for 15 minutes and then dried for 24 hours in a desiccator.

Kinetics Studies

Amount of 0.2 g each of the resins (CD, CTR, STR) where introduce into a 250 cm^3 conceal flask containing 30 cm^3 of 10 ppm solution of Pb(II) ions and agitated using platform shaking at the time range of 0.5, 5, 10, 30, 60 and 90 minutes and the percent adsorption of Pb(II) ion at different time were observed. The resulting solutions were filtered and analyze using bulk scientific atomic adsorption spectrometer.

Equilibrium Studies

Amount of 0.2 g each of the resins were introduced into five 250 cm^3 conical flask containing each of 30 cm^3 of (2, 4, 8, 10 and 15 ppm) of Pb(II) ions solutions. The mixture was agitated for 90 minutes and the resulting filtrate was analyzed using bulk scientific atomic adsorption spectrometer.

RESULTS AND DISCUSSION

Effect of Initial Concentration on Adsorption of Pb(II) ions by Resin

The adsorption off Pb(II) ion onto CD, CTR and STR as a function of initial concentration was studied at a temperature of 303K by varying the concentrations of the

metal in aqueous solution from 2-15 mg/dm^3 while keeping all other parameters constants. The result is shown in table 1 and figure 1 for CD, CTR and STR respectively. This shows that percentage adsorption of Pb(II) increase with increasing metal concentration and attains equilibrium between the metal concentration of 10-12 mg/dm^3 and decreases at much higher concentrations of 10-12mg/dm^3 which indicates that much energetically less favourable sites become involved with increasing metal concentration in aqueous solution [10,11].

The heavy metal uptake is attributed to different mechanisms of ion-exchange and adsorption process [10]. During the ion-exchange process, metal ions has to move through the pores of the CD, CTR and STR mass but also through the channels of the latice and they had to replace exchangeable ions (mainly sodium, calcium and magnesium) inside the resins. Metal ions uptake could mainly be attributed to the ion exchange reaction in the microspores of the adsorbents [10].

Table 1. Adsorption Pb (II) ions onto CD, CTR and STR at 303 K
Tablica 1. Adsorpcija Pb(II) na CD, CTR i STR na 303 K

C_O	C_e	X_e	% Absorption	C_e	X_e	% Absorption	C_e	X_e	% Absorption
2	0.70	1.90	65.00	0.96	1.04	52.00	1.03	0.97	48.00
4	0.94	3.06	76.50	1.35	2.65	62.5	1.91	2.09	55.25
8	2.04	5.96	74.50	1.81	6.19	77.38	3.00	5.00	62.50
10	3.27	6.73	67.3	1.92	8.08	80.80	1.91	4.59	45.90
15	2.45	10.55	83.7	2.74	12.26	81.73	7.90	7.10	67.33

pH = 70, Temperature = 303K, Particle size = 100-106µm Dosage = 0.2g,
Rate of agitation = 140rpm

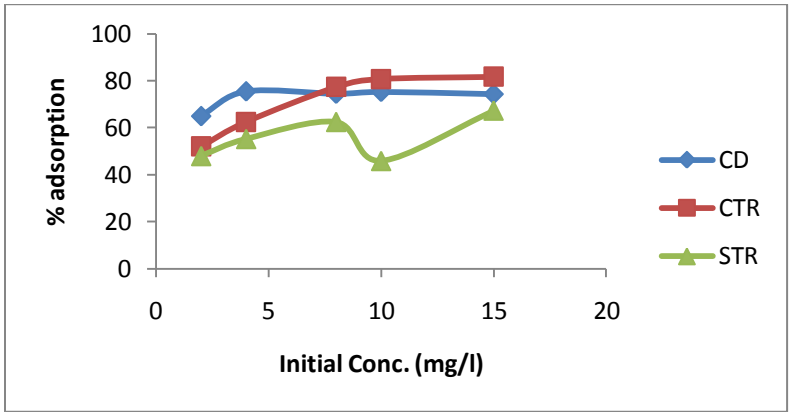

Figure 1. Plot of percentage adsorption with initial concentration for Coir dust (CD), Carboxylated toluenediisocyanate resin (CTR) and Sulphonated toluenediisocyanate resin (STR) at 303 K
Slika 1. Dijagram postotka adsorpcije s početnom koncentracijom kokosove prašine (CD), karboksilne toluenizocijanatne smole (CTR) i sulfonske tiocijanatne smole (STR) na 303 K

Isotherm Models

The sorption data has been subjected to different sorption models namely Freundluch and Florg-Huggins model.

Fraundlich Isotherm

The Freundlich sorption is one of the most widely used mathematical description which usually fits the experimental data over a wide range of concentration. This isotherm gives an expression encompassing the surface heterogeneity and the exponential distribution of active sites and their energies.

The Freundlich isotherm data is presented in table 2 for CD, CTR and STR and the model equation can be expressed in linear form as follows:

$$\text{Log}q_e = \log k_f + 1/n \log Ce \quad (1)$$

Where Ce is the equilibrium concentration in mg/l and q_e is the quantity of the metal ions sorbed into the adsorbents at equilibrium. The Freundlich model parameter and the statistical fits of the sorption data to this equation are given in figure 2, 3 and 4 for CD, CTR and STR respectively. The high correlation values of R^2 for both CD CTR and STR are (0.9006, 0.9447 and 0.9047) respectively indication the adsorption process can be effectively described by the Freundluch isotherm.

The constant K_F and n was calculated for the metal cation from the slope and intercept the plot. Values of K_F (0.087, 0.17, and 0.164) are related to temperature and is a characteristic constant for the adsorption system under study. Values of n between 2 and 10 shows good adsorption the numerical value of $1/n < 1$ (0.384, 0.98) for CD and STR indicates that sorption capacity has been exceeded at higher concentration and predicts unsaturation of the CD by the sorbate and also indicating multilayer adsorption. Conversely, $1/n > 1$(2.582) for CTR indicates that sorption capacity has been exceeded at higher concentrations and therefore predicts saturation of the sorbents by the sorbate and also indicates multilayer adsorption and finite surface coverage by the adsorbate on the adsorbents. The higher the sorbate concentration in the medium the more often the sorption capacity of the resin is exceeded with a desorption tendency.

Table 2. Fleundlich value for the Adsorption Pb (II) ions onto CD, CTR and STR at 303 K
Tablica 2. Freundlichove vrijednosti za adsorpciju olova (II) na CD, CTR and STR na 303 K

C_O	X_e	q_e	Log q_e	Log C_e	X_e	q_e	Logq_e	Log C_e	X_e	q_e	Log q_e	Log C_e
2	1.90	0.28	-0.55	-1.00	1.04	0.16	-0.80	0.02	0.97	0.14	-0.85	0.0
4	3.06	0.46	-0.34	-0.03	2.65	0.40	-0.40	0.13	2.09	0.31	-0.51	0.28
8	5.96	0.89	-0.05	0.31	6.79	0.93	-0.03	0.26	5.00	0.75	-0.12	0.48
10	6.73	1.01	0.004	0.51	8.08	1.21	0.08	0.28	4.59	0.69	-0.16	0.73
15	10.55	1.58	0.19	0.65	12.26	1.84	0.26	0.44	7.10	1.18	0.07	0.90

pH = 70, Temperature = 303K, Particle size = 100-106µm Dosage = 0.2g,
Rate of agitation = 140rpm

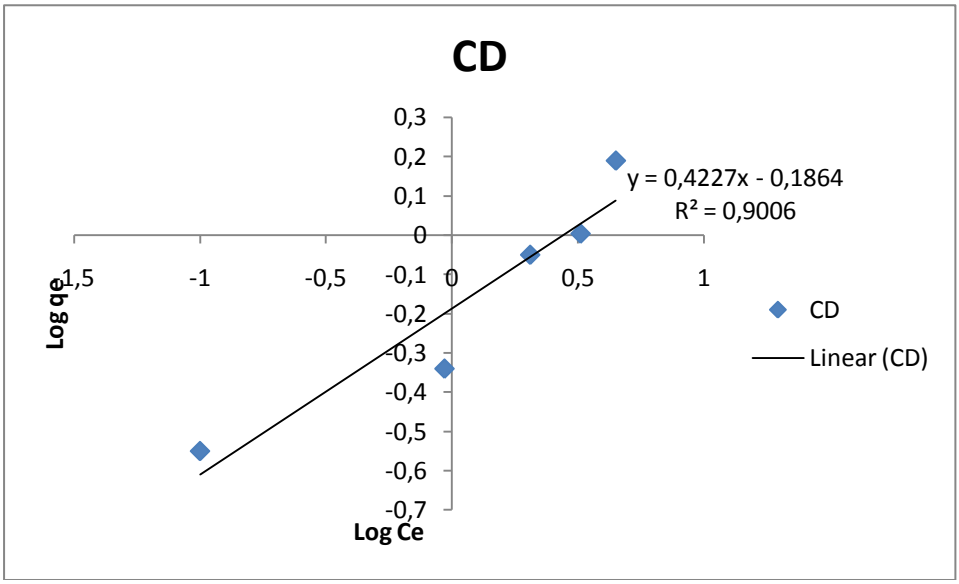

Figure 2. Freundlich Isotherm plot for Coir Dust (CD) at 303 K
Slika 2. Dijagram Freundlichove izoterme za kokosovu prašinu (CD) na 303 K

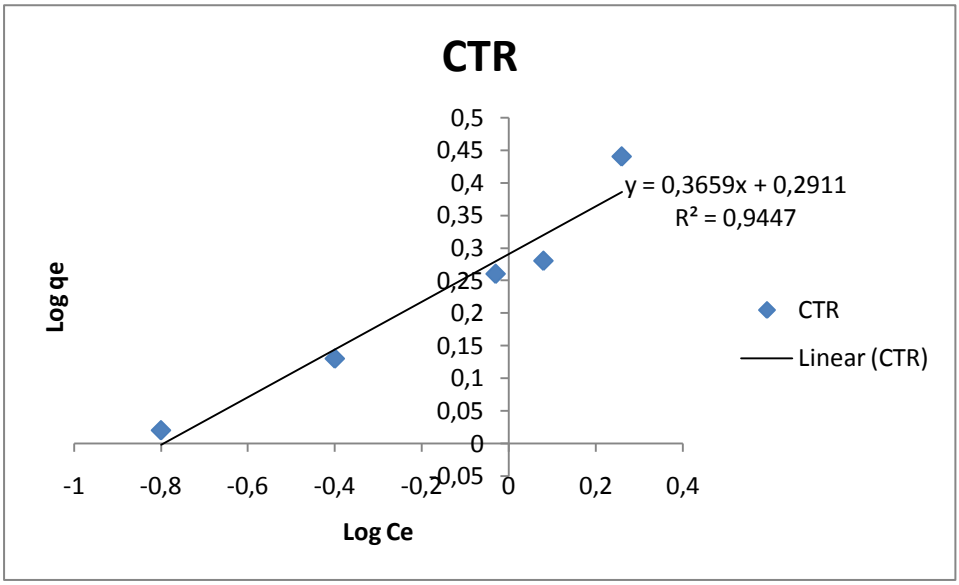

Figure 3. Freundlich Isotherm plot for Carboxylated Toluenediisocyanate Resin (CTR) at 303 K
Slika 3. Dijagram Freundlichove izoterme za karboksilnu toluenizocijanaznu smolu (CTR) na 303 K

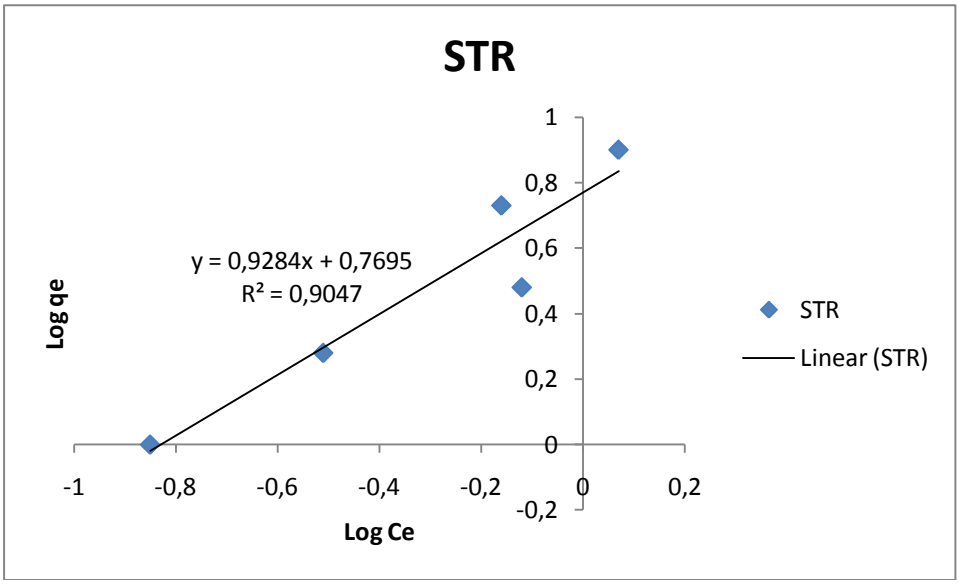

Figure 4. Freundlich Isotherm plot for Sulphonated Toluenediisocyanate Resin (STR) at 303 K
Slika 4. Dijagram Freundlichove izoterme za sulfonsku toluenizocijanaznu smolu (CTR) na 303 K

Flory-Huggins Isotherm

The Flony-Huggins isotherm has been used to describe the sorption of adsobate on adsobents and the result is presented in table 3. This model which helps to account for the degree of surface coverage characteristics of the adsorbate on the adsobents is expressed in a linear form as

$$\text{Log}^{\theta}/c_o = \log K_{FH} + \alpha_{FH} \log (1-\theta) \quad (2)$$

Where θ is the surface converge of the adsorbents by the adsobate $\theta = (1-c_o/c_e)$. C_o and C_e are the initial and equilibrium concentration of Pb(II) ions in solution respectively.

Table 3. Flory-Huggins valuefor the Adsorption Pb (II) ions onto CD, CTR and STR at 303 K
Tablica 3. Flory-Hugginsove vrijednosti za adsorpciju olova (II) na CD, CTR and STR na 303 K

	CD			CTR			STR		
C_O	θ	Log (1-θ)	Log $^{\theta}/_{Ce}$	θ	Log (1-θ)	Log $\frac{\theta}{C_o}$	θ	Log (1-θ)	Log (1-θ)
2	0.95	-1.30	-0.32	0.52	-0.32	-0.58	0.48	-0.29	-0.62
4	0.76	-0.63	-0.72	0.66	-0.47	-0.78	0.52	-0.32	-0.89
8	0.74	-0.59	-1.04	0.77	-0.64	-1.02	0.62	0.42	-1.12
10	0.67	-0.48	-1.15	0.81	-0.72	-1.09	0.46	-0.27	-1.34
15	0.70	-0.53	-1.33	0.82	-0.74	-1.26	0.47	-0.28	-1.50

pH = 70, Temperature = 303K, Particle size = 100-106µm Dosage = 0.2g,
Rate of agitation = 140rpm.

The plot of $\log\theta/C_o$ versus log (1-θ) is linear if the adsorption process conforms to this model. As shown in figure 5, 6 and 7 respectively the low correlation value of

(0.0057) for STR shows noncompliance of the data to this model whereas the relatively highly correlation value of R^2 (0.7964 and 0.9634) for CD and CTR indicates that the data can be described using this isotherm model. The equilibrium constant K_{FH} (0.022, 0.796, 0.045) and α_{FH} (-1.0561.465, -0.785) are obtained from the intercept and slope of the plot respectively.

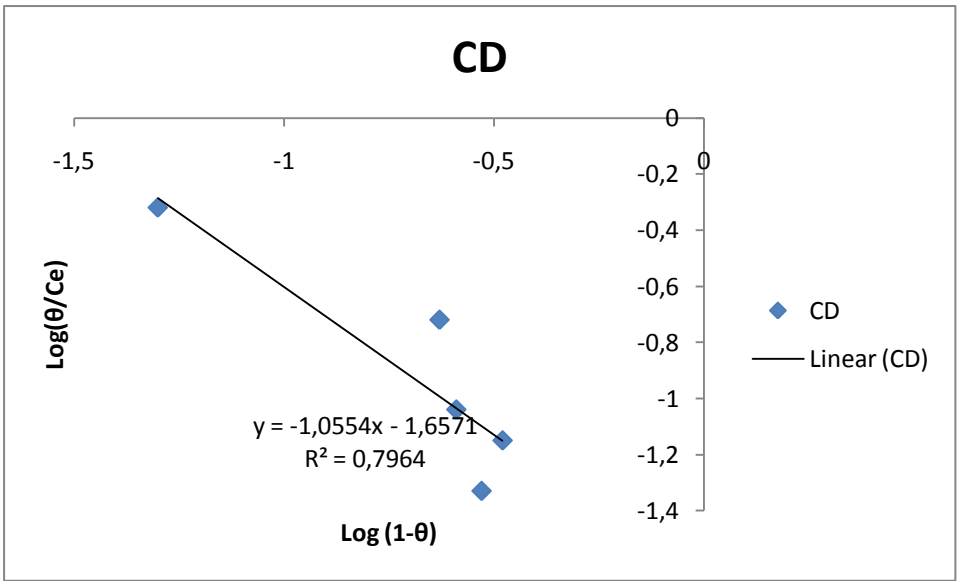

Figure 5. Flory-Huggins Isotherm plot for Coir Dust (CD) at 303 K
Slika 5. Dijagram Flory-Hugginsove izoterme za kokosovu prašinu (CD) na 303 K

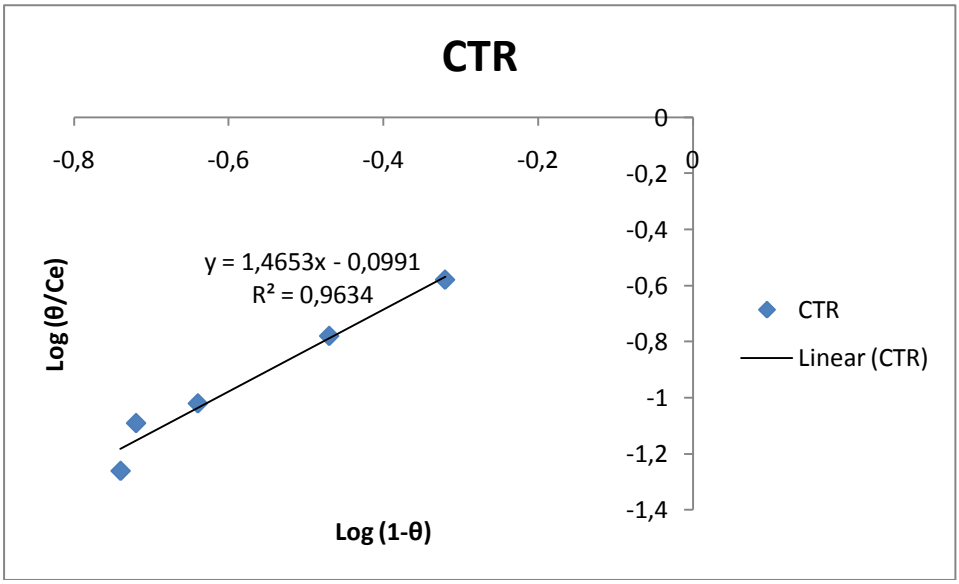

Figure 6. Flory-Huggins Isotherm plot for Carboxylated Toluenediisocyanate Resin (CTR) at 303 K
Slika 6. Dijagram Flory-Hugginsove izoterme za karboksilnu toluenizocijanaznu smolu (CTR) na 303 K

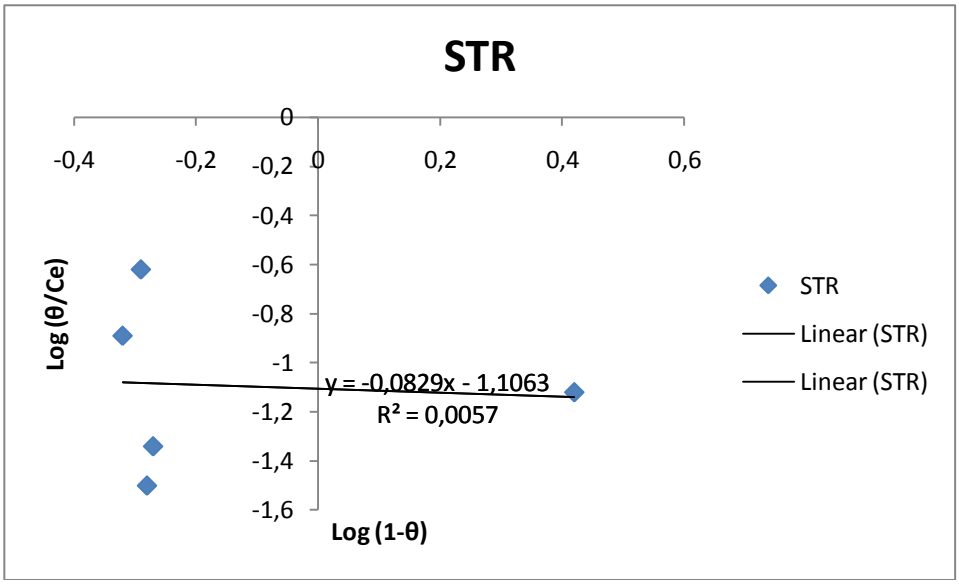

Figure 7. Flory-Huggins Isotherm plot for Sulphonated Toluenediisocyanate Resin (STR) at 303 K
Slika 7. Dijagram Flory-Hugginsove izoterme za sulfonsku toluenizocijanaznu smolu (CTR) na 303 K

The equilibrium constant α_{FH} from the Flory-Huggins model in related to the Gibb's free energy by the equation.

$$\Delta G^{O} = RT/n\ K_{FH} \qquad (3)$$

Where R is the universal gas constant = 8.314 JK^{-1} mol^{-1}, T is the absolute temperature (^{o}K) and K_{FH} is the Fory-Huggin's equilibrium constant. The ΔG^{o} (-9614.8, -574.9) value for Pb(II) adsorption onto CD and CTR are calculated and shown to be negative hence the process is spontaneous whereas the ΔG^{o} (7812.1) value for STR is shown to be positive indicating non-spontaneity of the process of adsorption of Pb(II) ion onto CTR.

Effect of Contact Time on Adsorption of Pb(II) by Resin

The adsorption data for the uptake of Pb(II) ions versus contact time for a fixed adsorbent dose of 0.2 g and with metal concentration of 10mg/l, particle size 100-106µm at pH 7.0 is shown in figure 8 CD, CTR and STR. The curves indicates increasing adsorption with time and attains equilibrium after 60 mins and this is the equilibrium concentration of metal ion (C_e) that can be sorbed at the reaction condition.

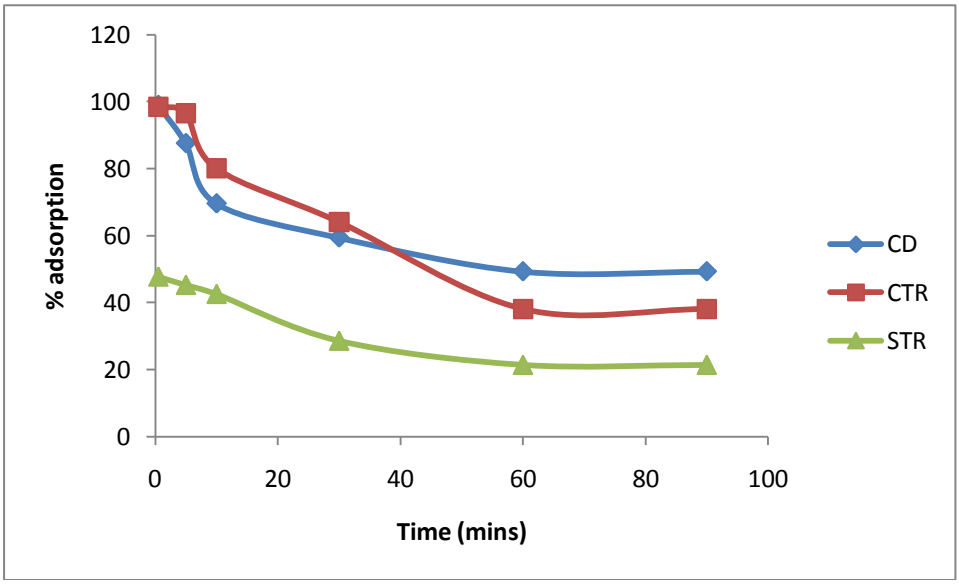

Figure 8. Plot of percentage adsorption with adrption time for Coir dust (CD), Carboxylated toluenediisocyanate resin (CTR) and Sulphonated toluenediisocyanate resin (STR) at 303 K
Slika 8. Dijagram postotka adrpcije s vremenom adsorpcije za kokosovu prašinu (CD), karboksilnu toluenizocijanatnu smolu (CTR) isulfonsku izocijanatnu smolu (STD) na 303 K

Pseudo-first-order kinetic model

The pseudo-first-order kinetic models was used to analyse the experimental result as follows:

$$log(q_e - q_t) = logq_e - \frac{K_i}{2.303} t \quad (4)$$

Hence a linear trace is expected between the two parameters, $\log(q_e - q_t)$ versus t, (Fig. 9) provided the adsorption follows pseudo-first-order kinetics. The values of k_1 and q_e can be obtained from the slope and intercept. The correlation coefficient are relatively higher, R^2 = (0.0603, 0.3535 and 0.8581) respectively for CD, CTR and STR showing the process of adsorption of Pb(II) ion onto CD, CTR and STR deviates greatly from the pseudo first order reaction mechanism for the adsorption of Pb(II) CD, CTR and STR.

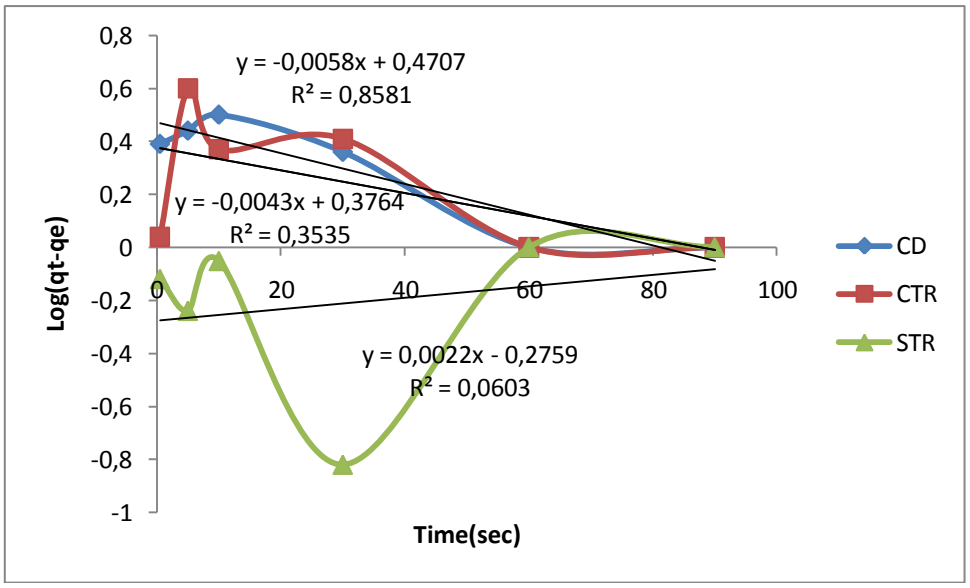

Figure 9. Pseudo-first-order Kinetics Plot Coir dust (CD), Carboxylated toluenediisocyanate resin (CTR) and Sulphonated toluenediisocyanate resin (STR) at 303 K
Slika 9. Dijagram kinetike pseudo–prvog reda za kokosovu prašinu (CD), karboksilnu toluenizocijanatnu smolu(CTR) i sulfo izocijanatnu smolu (STR) na 303 K

Pseudo-Second-Order kinetic model

The pseudo second order is given in the following linear form

$$t/q_t = 1/k_2\, q_e^2 + t/q_e \qquad (5)$$

The sorption rate constant k_2,(0.21, 4.47 and 2.25) and the sorption capacity q_e (0.41, 1.62 and 3.34) for CD, CTR and STR respectively are calculated from the slope and intercept of pseudo-second-order kinetic model plot (Fig. 10). The correlation coefficient are relatively higher, R^2 = (0.9974, 0.9851 and 0.9937) respectively for CD, CTR and STR showing the process of adsorption of Pb(II) ion onto CD, CTR and STR follows the pseudo second order reaction mechanism for the adsorption of Pb(II) CD, CTR and STR. The results kinetic of adsorption are shown in Tables 4-6.

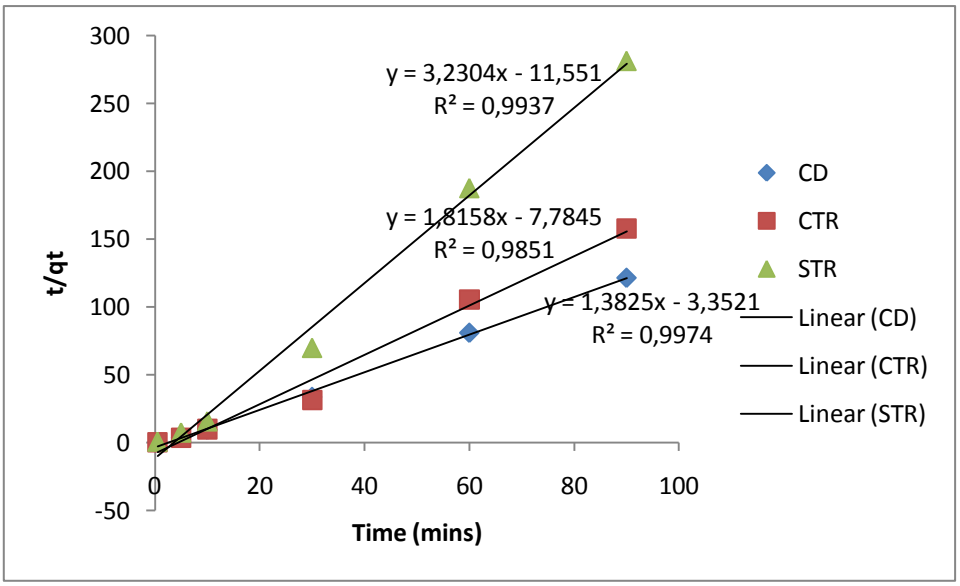

Figure 10. Pseudo-second-order Kinetics Plot Coir dust (CD), Carboxylated toluenediisocyanate resin (CTR) and Sulphonated toluenediisocyanate resin (STR) at 303 K
Slika 10. Dijagram kinetike pseudo–drugog reda za kokosovu prašinu (CD), karboksilnu toluenizocijanatnu smolu(CTR) i sulfo izocijanatnu smolu (STR) na 303 K

Table 4. Result of Kinetic Studies for the adsorption of Pb(II) ions onto Coir Dust (CD) at 303 K
Tablica 4. Rezultati kinetičke studije adsorpcije Pb(II) iona na kokosovoj prašini (CD) na 303 K

Time (mins)	C_t (mg/l)	X (mg/l)	q_t (mg/l)	A	ln(1-α)	Log(q_e-q_t)	D	t/q_t	$t^{1/2}$	% ion exchange
0.5	0.10	9.90	1.49	0.99	-4.61	- 0.12	99.00	0.34	0.71	99.00
5	1.24	8.76	1.31	0.88	-2.12	-0.24	27.06	3.81	2.24	87.60
10	3.04	6.96	1.04	0.70	-1.20	-0.52	12.29	9.61	3.16	69.60
30	4.06	5.94	0.89	0.59	-0.89	-0.82	1.46	33.70	5.48	59.40
60	5.07	4.93	0.74	0.49	-0.67	0.00	0.97	81.08	7.75	49.30
90	5.07	4.93	0.74	0.49	-0.67	0.00	0.97	121.62	9.49	49.30

Table 5. Result of Kinetic Studies for the adsorption of Pb(II) ions onto Carboxylated Toluenediisocyanate Resin (CTR) at 303 K
Tablica 5. Rezultati kinetičke studije adsorpcije Pb(II) iona na karboksilnoj toluendizocijanatnoj smoli (CTR) na 303 K

Time (mins)	C_t (mg/l)	X (mg/l)	q_t (mg/l)	A	ln(1-α)	Log(q_e-q_t)	D	t/q_t	$t^{1/2}$	% ion exchange
0.5	0.15	9.85	1.48	2.55	0.46	0.04	65.67	0.34	0.71	98.50
5	0.35	9.65	1.48	2.64	0.43	0.60	27.57	3.45	2.24	96.50
10	3.31	6.69	1.00	1.79	0.27	0.37	12.02	10.00	3.16	80.10
30	3.59	6.61	0.96	1.68	0.39	0.41	7.79	31.30	5.48	64.10
60	6.19	3.81	0.57	1.00	0.00	0.00	1.62	105.30	7.75	38.10
90	6.19	3.81	0.57	1.00	0.00	0.00	1.62	157.89	9.49	38.10

Table 6. Result of Kinetic Studies for the adsorption of Pb(II) ions onto Sulphonated Toluenediisocyanate Resin (STR) at 303 K
Tablica 6. Rezultati kinetičke studije adsorpcije Pb(II) iona na sulfonskoj toluendizocijanatnoj smoli (STR) na 303 K

Time (mins)	C_t (mg/l)	X (mg/l)	q_t (mg/l)	A	ln(1-α)	Log(q_e-q_t)	D	t/q_t	$t^{1/2}$	% ion exchange
0.5	5.22	4.78	0.72	2.23	0.21	0.39	0.92	0.69	0.71	47.80
5	5.47	4.53	0.68	2.12	0.11	0.44	0.83	7.40	2.24	45.30
10	5.74	4.26	0.64	1.99	0.01	0.50	0.74	15.63	3.16	42.60
30	7.14	2.86	0.43	1.34	1.08	0.36	0.40	69.76	5.48	28.60
60	7.86	2.14	0.32	1.00	0.00	0.00	0.27	187.50	7.75	21.40
90	7.86	2.14	0.32	1.00	0.00	0.00	0.27	281.25	9.49	21.40

CONCLUSION

The result obtained qualified that coconut coir dust (CD), carboxylated toluenediisocyanate resin (CTR) and sulphonated toluenediisocyanate resin (STR) are efficient adsorbent/ion exchanger for heavy metals adsorption from aqueous solutions. The adsorption of Pb(II) ions increased with increasing contact time reaching equilibrium at 60 minutes and pH of 7.0. the trend of efficiency of the adsorbent on adsorption was found to increase in the order CD> CTR> STR showing that coir dust as a natural adsorbent has more sorption sites and has high efficiency of metal ions uptake.

The equilibrium data fitted well to the Freundlich and Flory-Huggins isotherms.

The negative values of ΔG^o indicates that the processes were spontaneous and exothermic on the metal surface. Kinetic data confirms the applicability of the pseudo-second-order rate expression for the sorption of Pb(II) ions onto CD, CTR andSTR.

The sorption process attains equilibrium at 60minutes and waste effluents treated with these resins were in the limit cited by WHO for discharging into surface water or reuse for irrigation.

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