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Review IJA

Applications of Sesame Residues as Sorbents for Oil Removal from Produced Water

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Abstract

Large amounts of produced water are produced in tandem with the production of crude oil. Both dissolved and dispersed oil are present in produced water, which can contaminate the environment and pose health risks to people. In this study, the oil component, cadmium, and lead ions were extracted from the generated water using sesame residues and agricultural wastes. The sesame residues were dried, size-reduced, and ground. Standard techniques were used to produce the biosorbent and remove the lead, cadmium, and oil ions in a batch operation. After 30 minutes of equilibrium time and an initial oil concentration of 435.5 mg/l, biosorption experiments using the sesame pod and stalk demonstrated that both residues can be used to remove crude oil, cadmium, and lead ions from produced water. The removal rates for the sesame pod and stalk were nearly 96.7% and 97.2%, respectively, at an equivalent dosage of 1.0 g per liter of produced water. The findings of testing a number of kinetic models revealed that sesame stalk biosorbent followed a second-order kinetic model, while sesame pod biosorbent followed a pseudo-first-order kinetic model. Conversely, investigations using equilibrium isotherms showed that sesame stalks followed the Temkin isotherm whereas sesame pods followed.

Keywords: Sesame-residue, produced water, biosorption, biosorbent, kinetic models

INTRODUCTION

Because of the large amounts of water needed for oil production and the resulting effluence, the oil and gas sector are ranked as one of the eight most water-intensive industries. Produced water (PW) is water that is brought to the surface from underground formations during the extraction of gas or oil [1]. Billions of gallons of produced water generated globally on an annual basis [2] could be linked to more than 65,000 global onshore and offshore oil and gas fields [3]. During oil and gas explorations, produced water (trapped in subsurface formations) is brought to the surface which contains heavy metals (such as copper, cadmium, lead, chromium, mercury, silver, nickel, and zinc) as part of dissolved inorganic matter [4]. The amounts of heavy metals in generated water are mostly determined by the well's age and the geology of its development. Because they harm the ecology, these heavy metals should be appropriately controlled when the generated water is dumped into water bodies or spilled on the ground [5].

One of the biggest problems facing environmental scientists and technologists is still how to treat oil spills and water that have been contaminated by oil. Sorption is a common oil treatment method among those now in use since it is inexpensive, easy to use, and efficient [18]. Oil removal by biological waste materials has been reported by several authors [5, 7–14]. Growing environmental consciousness and concern in the 1970s prompted researchers to look for innovative ways to replace costly and dangerous chemical treatment procedures. Biosorption is becoming more and more popular because of these

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demands. Since biosorbent works well at low concentrations, it has been suggested as a substitute.

In this study, sesame pods and stalks were conditioned and tested for oil, cadmium, and lead ions uptake from produced water. Kinetic equilibria and isothermal studies on the data generated were carried out. Sorption of oil, cadmium ion, and lead ion were made at various loading rates, stirring speed, and sorption times.

MATERIALS

Sesame pods and stalks were collected from a farm site in Bartak village of Alkaleri local government area, Bauchi State, Nigeria. The crude oil was supplied by the Kaduna Refinery and Petrochemical Company (KRPC), which is based in Kaduna, Nigeria. In Jos, Nigeria, we purchased 1, 1, 1-trichloroethane from Chuzz Bond International. The chemicals and reagents were all analytical grades. The Gubi Dam Water Treatment Plant Laboratory in Bauchi, Nigeria, provided the distilled water. The sorbent materials (made by Ragaterm, Italy) were dried in an oven. Oil was extracted from water using separating funnels, and its presence was tested using a DR/2000 Spectrophotometer (HACH, Colorado, U.S.A.). The pH of the combinations was measured using a Hanna pH meter. A JJ-4 six-couplet digital electric mixer (Search Tech Instrument, England) was used to carry out sorption research. The sesame pod and stalk were ground into a powder using a laboratory mortar and pestle, and sieves were used to separate the material into different sizes (212–63 microns).

METHODS

Biosorbent Preparation

After multiple water washes, the sesame stalk and pod were allowed to air dry. To get rid of all the color pigments in a reflux condenser, the dried sesame pod and stalk were ground into particles that ranged in size from two to three millimeters. After being treated with n-hexane, the sesame pod and stalk were cleaned with distilled water and allowed to dry for 24 hours at 700°C in an oven. These were then preserved in airtight, sealed plastic containers marked SPB (Sesame Pod Biosorbent) and SSB (Sesame Stalk Biosorbent), respectively, after being further crushed and sieved through a 212–63-micron sieve.

Simulation of the Produced Water

One liter of distilled water and 435.5 milligrams of crude oil were combined in the lab to create the generated water. A pH meter was used to measure and record the produced water's pH. An atomic absorption spectrophotometric study (AAS) was conducted on the simulated produced water to determine the amount of cadmium and lead ions in the mixture, and the results were recorded.

Experimental Design

In this current study, design-expert software (Version 13.0) was used for experimental design. A collection of statistical and mathematical tools for planning trials and maximizing the impact of process factors is known as the response surface methodology (RSM). Three independent variables' correlation (i.e., biosorbent dosage, X_1; stirring speed, X_2; and contact time, X_3) and dependent variables (residual oil, Y1; residual cadmium ion, Y2; and residual lead ion, Y3) were investigated through CCD at three different levels denominated as (–1, 0, +1). The layout can be viewed as three-level partial factorials. To optimize the three variables that showed significant effects on the oil removal capacity of both sesame pod and stalk, a 2k factorial CCD was used to construct a total of 20 tests with eight cube points plus six center points and six axial points. Fisher's exact test and p-values were used in an analysis of variance (ANOVA) to ascertain the effects of each independent variable on responses and model quality. The matrix design for the experiment is presented in Table 1.

Table 1. Experimental design for removal of oil and heavy metals from produced water.

Run	Dosage (g/l)	Time (min)	Speed (rpm)	Residual Oil (mg/l)	Cadmium Ion (mg/l)	Response Lead Ion (mg/l)
1	0.10	30.00	50.00			
2	0.55	38.52	150.00	–	–	–
3	0.55	17.50	150.00	–	–	–
4	1.00	5.00	250.00	–	–	–
5	0.55	17.50	150.00	–	–	–
6	0.55	17.50	150.00	–	–	–
7	0.55	17.50	150.00	–	–	–
8	0.10	5.00	50.00	–	–	–
9	0.10	30.00	250.00	–	–	–
10	0.55	17.50	150.00	–	–	–
11	1.00	30.00	250.00	–	–	–
12	0.10	5.00	250.00	–	–	–
13	1.31	17.50	150.00	–	–	–
14	0.55	3.52	150.00	–	–	–
15	0.55	17.50	318.18	–	–	–
16	1.00	30.00	50.00	–	–	–
17	0.55	17.50	150.00	–	–	–
18	1.00	5.00	50.00	–	–	–
19	0.21	17.50	150.00	–	–	–
20	0.55	17.50	18.18	–	–	–

Batch Adsorption Experiments

The experiments were carried out by taking 500 ml of 435.5 mg/l laboratory synthesized produced water and different quantities of the prepared sorbent materials (0.10, 0.55, 1.0, and 1.31 grams) each in 1000 ml glass beakers. The different adsorbent dosages were obtained using the design-expert software by means of response surface methodology (RSM) as given in Table 1. The flasks were then agitated at various stirring speeds, as 50–250 rpm and at various contact times, e.g., 10–40 minutes. The stirring speed and the contact time were also obtained using a central composite design. With the aid of a jar test set-up, the mixtures were agitated at the given time and stirring speeds. The biosorbents and sorbates were then separated using a 63-micron sieve. After separating the biosorbent from the mixture, the residual oil in the mixtures was then extracted and measured with the aid of a UV/VIS spectrophotometer, and an AAS analysis was also carried out to determine the amount of residual cadmium and lead ions in the various samples, respectively. The same procedure was followed for all the 20 runs obtained from CCD for each of the two adsorbents (sesame pod and stalk).

RESULTS AND DISCUSSIONS

Effects of SPB Dosage

The design matrix shown in Table 1 was used to conduct the batch adsorption experiment. Effects of biosorbent dosage (sesame pod), contact time, and stirring speed were determined and the results are presented in Table 2.

As shown in Table 2, the results indicated that runs 13, 14, 15, 19, and 20 are out-layers and therefore were not considered in choosing the best treatment option. From the results obtained, it could be observed that there was a reduction in the concentration of residual oil with an increase in the concentration of the bio-sorbent dosage (Sesame pod). At run 1, when the amount of bio-sorbent was 0.1 g, the residual oil was found to be 310 mg/L, which is equivalent to 28.8% removal.

Runs 16 and 18 gave residual oil removal of 15 mg/L and 28 mg/L, respectively which were within the acceptable limit of 30 mg/L set up by the Department of Energy and Climate Change (DECC) for oil in produced water discharged into seas. In addition, the residual cadmium and lead ions were 0.015 and 0.018 mg/L, respectively which were slightly above the maximum limit of 0.005 mg/l for cadmium ions in drinking water set up by the World Health Organization (WHO).

However, the residual Pb^{2+} for run 16 was found to be below the 0.015 mg/L set by WHO. Therefore, run 16 was chosen as the best treatment option.

Table 2 presents the results obtained on biosorption of oil, cadmium, and lead ions from produced water using sesame pod biosorbent (SPB).

Table 2. Effects of SPB loading rate on oil, lead, and cadmium ions removal from produced water.

Run	Dosage (g)	Time (Min)	Stirring Speed (rpm)	Residual Oil (mg/L)	Residual Cadmium Ion (mg/L)	Residual Lead Ion (mg/L)
1	0.10	30.00	50.00	310.00	2.146	1.269
2	0.55	38.52	150.00	118.00	0.425	0.534
3	0.55	17.50	150.00	120.00	0.427	0.536
4	1.00	5.00	250.00	30.00	0.018	0.013
5	0.55	17.50	150.00	120.00	0.422	0.537
6	0.55	17.50	150.00	120.00	0.422	0.537
7	0.55	17.50	150.00	120.00	0.422	0.537
8	0.10	5.00	50.00	311.00	2.150	1.272
9	0.10	30.00	250.00	309.00	2.143	1.266
10	0.55	17.50	150.00	120.00	0.422	0.537
11	1.00	30.00	250.00	32.00	0.012	0.010
12	0.10	5.00	250.00	305.00	2.149	1.275
13	1.31	17.50	150.00	45.00	0.017	0.012
14	0.55	3.52	150.00	100.00	0.425	0.539
15	0.55	17.50	300.00	110.00	0.423	0.535
16	1.00	30.00	50.00	15.00	0.015	0.011
17	0.55	17.50	150.00	120.00	0.422	0.537
18	1.00	5.00	50.00	28.00	0.018	0.015
19	0.21.81	17.50	150.00	320.00	2.146	1.249
20	0.55	17.50	18.18	123.00	0.425	0.538

Effects of Sesame Stalk Biosorbent (SSB) Dosage

Table 3 presents the results obtained on biosorption of oil, cadmium, and lead ions from water using sesame stalk biosorbent (SSB). As seen from the results in Table 3, there was an increase in oil removal as the concentrations of the bio-sorbents were increased for the sesame stalk biosorbent. For the sesame stalk, the residual oil was found to be 295 mg/L at a 0.1 g dose of the bio-sorbent, which is equivalent to 32.3% oil removal. At run 11, this was found to decrease up to a concentration of 12 mg/L (97.24% oil removal) at a concentration of 1.0 g of the sesame stalk bio-sorbent which was within the acceptable limit set up by the Department of Energy and Climate Change (DEEC). A concentration of 30 mg/L performance standard is the regulation limit for oil concentration in generated water released into the sea. At run 18, the residual oil was found to be 18 mg/L while the residual cadmium and lead ions were 0.026 mg/L and 0.023 mg/L, respectively. The residual lead ion at run 18 falls within the standard limit of 0.05 mg/L set up by WHO hence run 18 was chosen as the best treatment option. Similar findings were reported by Veil (2019) [15] and Wong et al. (2020) [16]. Furthermore, from the table, it can be observed that the amount of organic biosorption increased with an increase in biosorbent dosage. This result can be explained by the fact that for optimum biosorption, extra sites must be available for biosorption reaction, whereas by increasing the biomass concentration, the number of sites available for biosorption increased; this agrees with the results published by different authors, such as [17, 18, 19].

Table 3. Effect of SSB loading rate on oil, cadmium, and lead ion removal from produced water.

Run	Dosage (g)	Time (min)	Stirring Speed (rpm)	Residual Oil (mg/L)	Residual Cadmium Ion (mg/L)	Residual Lead Ion (mg/L)
1	0.10	30.00	50.00	295.00	2.342	1.94
2	0.55	38.52	150.00	132.00	1.191	0.551
3	0.55	17.50	150.00	105.00	1.195	0.552
4	1.00	5.00	250.00	23.00	0.025	0.024
5	0.55	17.50	150.00	105.00	1.195	0.552
6	0.55	17.50	150.00	105.00	1.195	0.552
7	0.55	17.50	150.00	105.00	1.195	0.552
8	0.10	5.00	50.00	308.00	2.346	1.843
9	0.10	30.00	250.00	301.00	2.341	1.838
10	0.55	17.50	150.00	105.00	1.195	0.552
11	1.00	30.00	250.00	12.00	0.020	0.021
12	0.10	5.00	250.00	315.00	2.343	1.842
13	1.31	17.50	150.00	40.00	0.022	0.024
14	0.55	3.52	150.00	111.00	1.196	0.555
15	0.55	17.50	318.18	103.00	1.188	0.551
16	1.00	30.00	50.00	16.00	0.021	0.020
17	0.55	17.50	150.00	105.00	1.195	0.552
18	1.00	5.00	50.00	18.00	0.26	0.023
19	0.21	17.50	150.00	300.00	2.343	1.841
20	0.55	17.50	18.18	108.00	1.197	0.553

Adsorption Isotherms

Experimental sorption data are described using equations for equilibrium isotherms. Among the different models that have been published in the literature to describe experimental data on adsorption isotherms, the Langmuir and Freundlich models are the most frequently used. These equilibrium models' equation parameters and underlying thermodynamic presumptions frequently shed light on the sorption mechanisms as well as the sorbents' surface characteristics and affinity. The equations' coefficients and symbols are defined.

The Freundlich Isotherm

In 1906, Freundlich presented the earliest known sorption isotherm equation (Freundlich, 1906). This empirical model, which is represented by the following equation, can be used for both multilayer sorption and non-ideal sorption on heterogeneous surfaces:

$$q_e = a_f C_e^{\mathrm{bF}} \tag{1}$$

where the Freundlich isotherm constant is denoted by a_F. Ce solution phase oil concentration at equilibrium, mg dm^{-3}, the Freundlich constant has been computed under the assumption of an exponentially declining sorption site energy distribution. Since it doesn't reduces to Henry's law at low concentrations, it is frequently criticized for missing a basic thermodynamic foundation. The linearized Freundlich equation can be used (Equation 2):

$$ln_{qe} = ln_{aF} + \mathrm{b_F} ln_{Ce} \tag{2}$$

A plot of ln_{qe} versus ln_{Ce} is a straight line with slope, b_F, and intercept ln_{aF} (Figure 1).

Figure 1 presents the Freundlich isotherm plot for SPB and SSB. The broken lines represent sesame pod while the continuous line represents that of stalk.

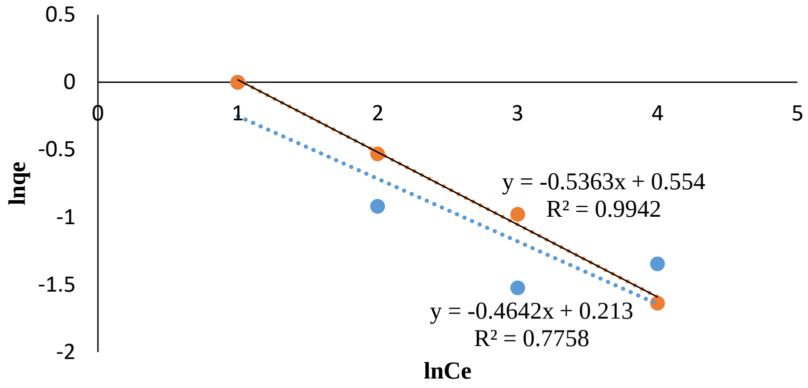

Figure 1. Freundlich isotherm plot of SPB and SSB.

The Langmuir Isotherm

A theoretical equilibrium isotherm that links the quantity of gas sorbed on a surface to the gas's pressure was created by Langmuir. The most well-known and frequently used sorption isotherm is most likely the Langmuir model. It can be shown as follows in Equation 3 (Ho et al., 2013) and has demonstrated strong agreement with a wide range of experimental data: Many monolayer adsorption techniques have found success utilizing the Langmuir adsorption isotherm, which proposes that adsorption occurs at homogenous locations within the adsorbent. The linearized Langmuir can be used (Equation 4) [20]:

$$q_e = \frac{K_L bCe}{1+K_L C_e} \tag{3}$$

$$\frac{Ce}{qe} = \frac{1}{bk_L} + \frac{1}{b}\mathrm{Ce} \tag{4}$$

where b is the substrate's adsorption capacity (gram solute/gram adsorbent), kL is a constant that represents the strength of the solute's bond with the substrate (L/mg), C_e is the sorbate's equilibrium concentration (milligrams per liter), and qe is the amount of sorbate per unit mass of the biosorbent (milligrams per gram). A straight line with a slope of 1/b and an intercept of 1/(bk_L) is produced when Ce/q_e is plotted versus Ce for SPB and SSB, while q_e is expressed using Equation (5).

$$q_e = \frac{V(Ci-Ce)}{m} \tag{5}$$

where V is the biosorption volume (liters), Ci is the initial concentration of the sorbate (milligrams per liter) and m is the mass of the biosorbent (gram).

The dimensionless equilibrium parameter, RL, which is given by the following, can be used to express the fundamental properties of the Langmuir

$$R_L = \frac{1}{1+bC0} \tag{6}$$

where b is the Langmuir's adsorption constant (L/mg) and C0 is the maximum initial solute concentration. The type of isotherm is indicated by the value of RL, which can be either irreversible (RL = 0), favorable (0 < RL < 1), linear (RL = 1), or unfavorable (RL > 1). Figure 2 presents the Langmuir isotherm plot of SPB and SSB.

Dubinin-Radushkevish Isotherm

The DubinRin-Radushkevish isotherm was used to assess the apparent energy of adsorption and the porosity properties of the biomass. The model is depicted as:

$$q_c = q_D \exp\left(-B_D \left[RT\, ln_{\left(1+\frac{1}{Ce}\right)}\right]^2\right) \tag{7}$$

where q_D is the Dubinin-Radushkevich isotherm constant associated with the degree of sorbate sorption by the biosorbent surface, and B_D is the free energy of sorption per mole of the sorbate as it migrates to the surface of the adsorbent from an infinite distance in the solution. The linear form of Equation (3) is given as:

$$ln_{qc} = ln_{qD} - 2B_D RT\, ln_{\left(1+\frac{1}{Ce}\right)} \tag{8}$$

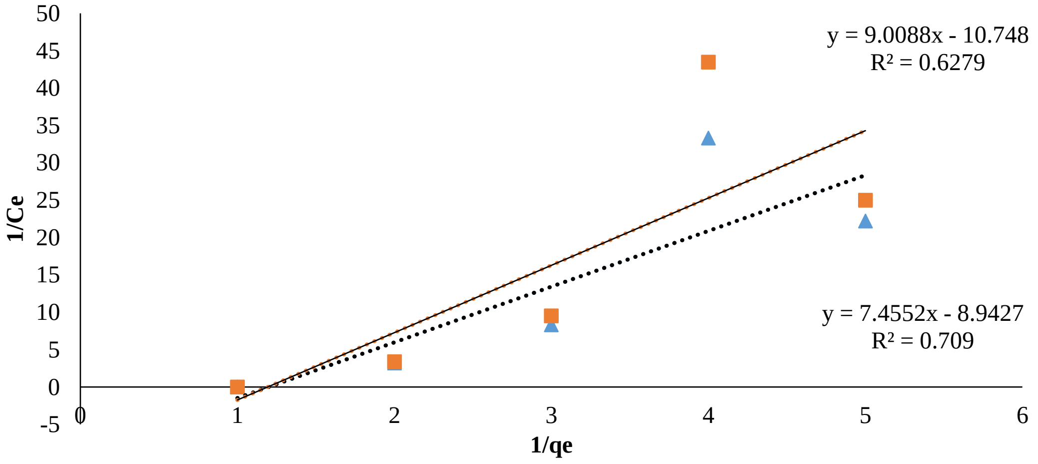

Figure 2. Langmuir isotherm plot of SPB and SSB.

Figure 3 presents the plot of Dubinin Radushkevish for sesame pod and stalk biosorbent. The dotted line represents the plot of a Sesame pod while the continuous line represents that of the Sesame stalk. As seen from the diagram, the plot of qe against ln(Ce +1/Ce) gave a straight line with an R^2 values of 0.8525 and 0.8871 for the sesame pod and stalk.

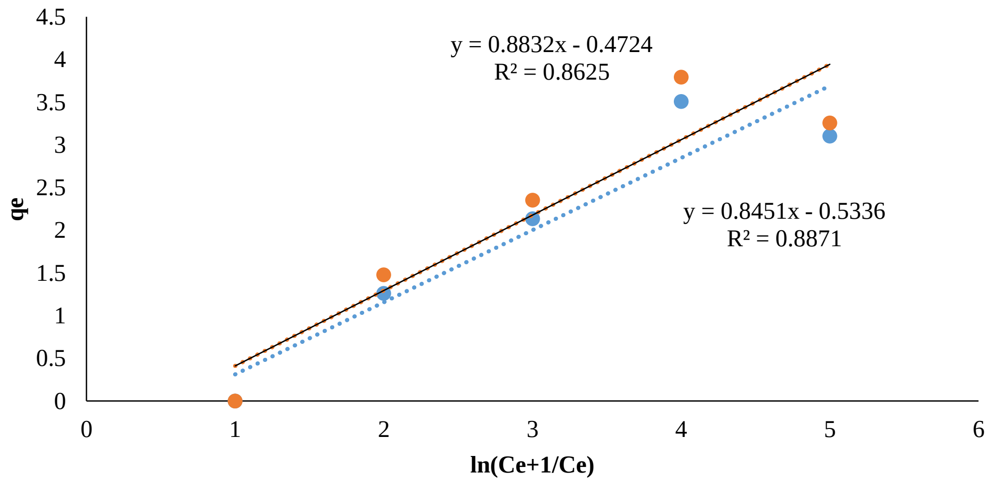

Figure 3. Dubinin Radushkevish plot for SPB and SSB.

The Temkin Isotherm

The Temkin isotherm is derived from the assumption that the decrease in the heat of sorption is linear, as opposed to logarithmic, as the Freundlich equation suggests. According to Ho et al. (2013), the Temkin isotherm is typically used as follows [20]:

$$q_c = \frac{RT}{b} ln_A + \frac{RT}{b} ln_{Ce} \tag{9}$$

where T is the absolute temperature, R is the universal gas constant, and A and b are constants that are set by the biosorbent.

Figure 4 shows the graphical representation of Temkin isotherm for sesame pod and stalk. As seen from the figure, a plot of qe against logCe was obtained with a correlation coefficient (R^2) value of 0.8909 for the sesame pod and 0.8731 for the stalk.

Tables 4 and 5 present the evaluated isotherm constants for SPB and SSB. From the results presented in the tables, it can be deduced that the biosorption of oil using SPB follows Temkin isotherms having an R^2 value of 0.8909 while the biosorption of oil using SSB followed the Freundlich model with a correlation coefficient of 0.9942. The fact that the biosorption of oil using SPB and SSB does not follow Langmuir isotherm, means that the mechanism of biosorption is multilayer adsorption of active sites.

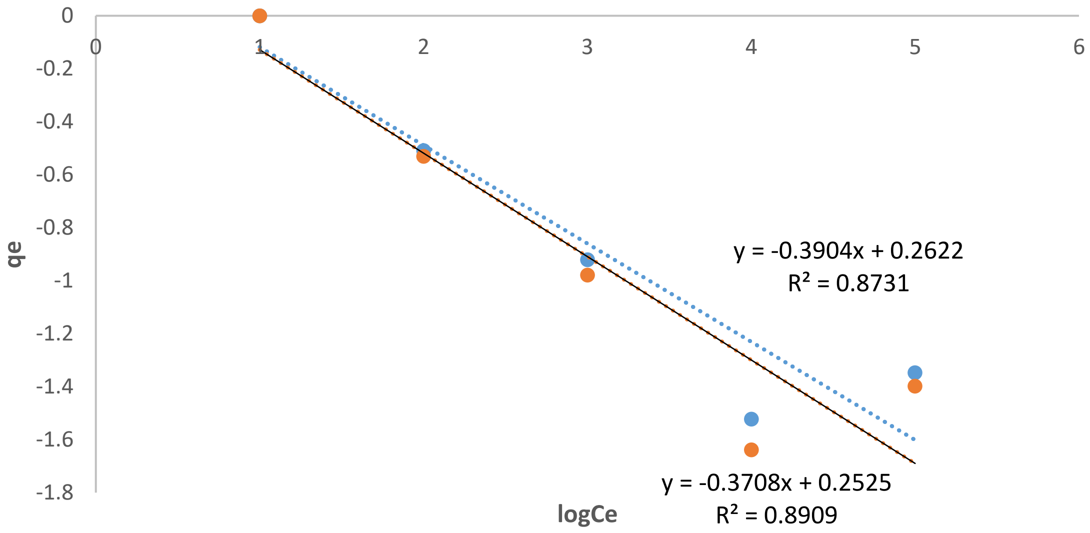

Figure 4. Temkin isotherm plot of SPB and SSB.

Table 4. Evaluated isotherms constants for SPB.

Isotherm	**Slope**	**Intercept**	**R^2**
Langmuir	7.4552	–8.9427	0.709
Freundlich	–0.4642	0.213	0.7758
Dubinin	0.512	1.6065	0.8871
Tempkin-Pycher	*–0.3708*	*0.2525*	*0.8909*

Table 5. Evaluated isotherms constants for SSB.

Isotherm	**Slope**	**Intercept**	**R^2**
Langmuir	9.008	–10.748	0.6279
Freundlich	*0.5363*	*0.554*	*0.9942*
Dubinin	0.8832	–0.4724	0.8625
Tempkin-Pycher	–0.390	0.2622	0.8731

Kinetic Studies

To clarify the process of solute adsorption, numerous kinetic models have been put forth. The wastewater treatment process can be designed and optimized with the use of these kinetic models. The following four (4) kinetic models were taken into consideration to examine the mechanism of oil biosorption by SPB and SSB. To identify the rate-limiting processes in the biosorption of oil and heavy metal ions onto SPB and SSB, pre-equilibrium kinetic profiles were described. The first-order equation (Equation (10)), Lagergren Pseudo-first order (Equation (11)) and pseudo-second order (Equation (12)) kinetic models were applied in the biosorption of nickel on spent activated clay [21], reactive black 5 dye by *Aspergillus foetidus* [22], biosorption of Acid Red 57 by dried *Cephalosporium aphidicola* cells [23], and biosorption of Cu^{+2} unto banana peel.

First-Order Kinetic Model

The general form of the first-order kinetic model is given in Equation (7):

$$\frac{l}{qt} = \frac{l}{qe} + \frac{kl}{qe^{t}} \tag{10}$$

Figure 5 presents the first-order kinetic plot of SPB and SSB. The broken line represents SPB while the continuous line represents SSB. As seen from the figure, the kinetic data did not fit well into the first-order kinetic model.

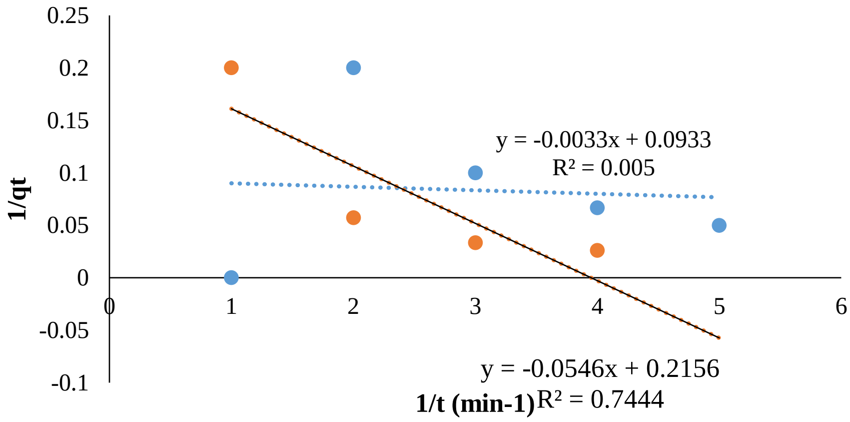

Figure 5. First-order kinetic model for SPB and SSB.

Lagergren Pseudo First-Order Kinetic Model

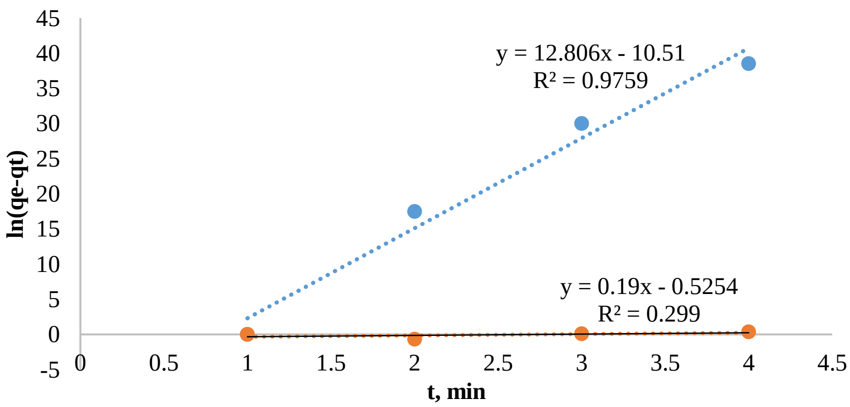

Figure 6. Pseudo-first-order kinetic model of SPB and SSB.

The model that Lagergren suggested, the integrated linear version of the pseudo first-order kinetic model, is

$$\ln(q_e - q_t) = \ln q_e - \mathrm{kt} \tag{11}$$

where q_e is the quantity of dye adsorbed at equilibrium (mg/g), qt is the amount of oil adsorbed at time t (mg/g), and k1 is the first order rate constant (min^{-1}). Thus, a linear relationship between the two parameters log ($q_e - q_t$) and t is expected if the biosorption proceeds according to first-order kinetics. The values of k_1 and q_e can be determined using the slope and intercept. The R2 (0.9759) and q_e indicate that the biosorption of oil onto SPB fits pseudo-first-order kinetics quite well. However, the SSB R2 value of 0.299 indicates that the biosorption data did not fit pseudo-first-order kinetics well. As a result, the oil biosorption onto SSB might not occur at the pseudo-first-order rate expression (Figure 6).

Second-Order and Pseudo-Second-Order Kinetics

A second-order or pseudo-second-order kinetic model may also be used to explain the biosorption. The second order and pseudo-second-order models' linearized forms are as follows (Figures 7 and 8):

$$\frac{1}{C_e} = \mathrm{k2t} + \frac{1}{C_0} \tag{12}$$

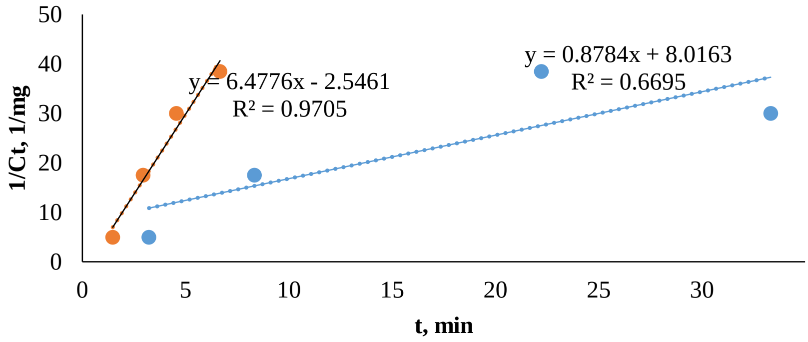

Figure 7. Second-order kinetic plot of SPB and SSB.

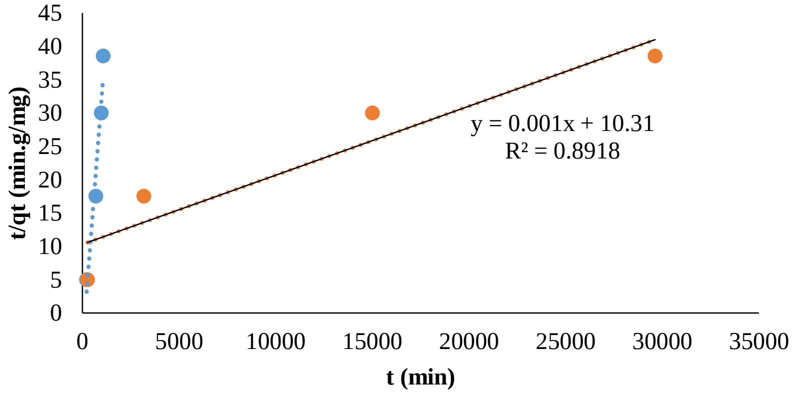

Figure 8. The pseudo-second-order kinetic plot of SPB and SSB.

$$\frac{t}{qt} = \frac{1}{k2q^2} + \frac{1}{q_e}\mathrm{t} \tag{13}$$

where the second-order rate constant (g/mg min) is denoted by k2. If the adsorption is second order or pseudo-second order, then $\frac{1}{q_e}$ vs t and $\frac{t}{q_t}$ vs t should be linear. The plots' slopes and intercepts can be used to compute q_e and k_2.

The kinetic parameters of various kinetic models using SPB are summarized in Table 6.

Table 6. Kinetic parameters of various kinetic models using SPB.

Kinetics	**Slope**	**Intercept**	**R^2**
First order	–0.0033	0.0933	0.005
Pseudo-first order	*12.806*	*–10.51*	*0.959*
Second order	0.8784	8.0163	0.6695
Pseudo second order	0.0375	–4.9681	0.9524

As seen from Table 6, the adsorption of oil from produced water using sesame pod biosorbent follows a pseudo first-order kinetic model with a correlation factor (R^2) of 0.959.

The kinetic parameters of various kinetic models using SPS are summarized in Table 7.

Table 7. Kinetic parameters of various kinetic models using SSB.

Isotherm	**Slope**	**Intercept**	**R^2**
First order	–0.0546	0.2158	0.7444
Pseudo-first order	0.19	–0.524	0.299
Second order	*6.4776*	*–2.5461*	*0.9705*
Pseudo second order	0.001	10.31	0.8918

As seen from Table 7, it can be deduced that the adsorption of oil using SSB can be described much better by the second-order kinetic model than the Pseudo second-order model. The R2 value was found to be 0.9705, which is the highest among the four different kinetic models tested.

CONCLUSIONS

Biosorbents were prepared from sesame pods and stalk. Using batch adsorption, biosorption parameters, such as the impact of loading rate, contact time, and stirring speed were investigated. According to the results, both may be used to remove lead ions, cadmium, and oil (both dissolved and dispersed) from generated water, with 96.7% removal for SPB and 97.2% removal for SSB, respectively at an equivalent dose of 1 g of the biosorbents in produced water at an initial oil concentration as high as 435.5 mg/l. Sesame stalk biosorbent followed a second-order kinetic model, while sesame pod biosorbent followed a pseudo-first-order kinetic model, according to the findings of tests of several biosorption kinetic models. Equilibrium isotherm studies on the other hand revealed that SPB followed the Temkin isotherm while SSB followed the Freundlich isotherm model indicating a multilayer adsorption of oil on the SPB and SSB surface.

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