

Biosorption and Kinetic Studies on Oil Removal from Produced Water Using Banana Peel

U.A. El-Nafaty*, I.M. Muhammad and S. Abdulsalam

Chemical Engineering Programme, Abubakar Tafawa Balewa University PMB 0248, Bauchi-Nigeria

*Corresponding author: elnafaty@gmail.com

Abstract

Crude oil production is accompanied by generation of large volumes of produced water. The produced water contains both dissolved and dispersed oil and these pose health hazards to human health and contamination of the environment. In this work, banana peel, an agricultural waste was used to remove the oil component from produced water. The peel samples were dried, size-reduced and characterized for functional groups, surface morphology, elemental composition and surface area using FTIR, SEM, EDS, and BET analytical equipment respectively. Standard methods were employed for the production of biosorbent and removal of oil using batch process. The result of EDS spectroscopy revealed that the peel contained 88.52% C; 5.69% O; 2.19% Si; 2.80% K; and 0.80% Ca. Biosorption study with the peel showed that it can be used in the removal of oil (dissolved and dispersed oil) from produced water providing almost complete removal at an equivalent dosage of 267 mg banana peel per litter produced water after 35 minutes equilibrium time and initial oil concentration as high as 194 mg/l. Solution pH, loading rate, sorption time, and temperature effects were studied. Several biosorption kinetic models were tested and the result showed that banana peel biosorbent followed pseudo-second-order kinetics. Equilibrium isotherm studies on the other hand revealed that banana peel closely followed the Langmuir isotherm model.

Keywords: banana peel, produced water, biosorption, kinetic models

1.0 Introduction

Treatment of oil spills and oil contaminated water remains one of the major challenges to environmental scientists and technologists. Among the existing techniques used for oil treatment, sorption is a popular technique because it is cheap, simple and effective (Banerjee *et al.*, 2006). Among the various sorbents used, banana peel appears to be attractive material in terms of cost, versatility and abundance (Muhammad, 2012). Oil removal by biological waste materials have been reported by several authors [Khaled *et al.*, (2011); Lin *et al.*, (2011); Othman *et al.*, (2008); Pasila, (2004); Suni *et al.*, (2004); Tania *et al.*, (2000); Vlaev *et al.*, (2011); Banerjee *et al.*, (2006); Muhammad *et al.*, (2012) and Muhammad *et al.*, 2012]. During the 1970s increasing environment awareness and concern led to search for new techniques to replace expensive/hazardous chemical treatment methods. These demands had led to increasing interest in biosorption. The use of biosorbent has been proposed as an alternative, as it has proven effective on low concentrations.

The biosorption process involve a solid phase (sorbent or biosorbent; biological material) and a liquid phase (solvent, normally water) containing a dissolved species to be sorbed (sorbate, metal ions). Due to higher affinity of the sorbent to the sorbate species, the later is attracted and removed by different mechanisms. The process continues till equilibrium is established between the amount of the solid-bound sorbate species and its portion remaining in the solution. The degree of sorbent affinity for the sorbent determines its distribution between the solid and liquid phases. The major advantages of biosorption over conventional treatment methods include low cost, high efficiency, minimized chemical and biological sludge, and regenerability. Many workers have reported using biological waste materials to treat different pollutants ranging from metals to organic dyes found in waste water. For example, AjayKumar *et al.*, (2009) studied biosorption of Cadmium, Copper, Nickel, and Zinc in aqueous solution on activated sludge. Nowicki *et al.*, (2010) investigated the sorption properties of walnut shell while Suni *et al.*, (2004) utilized cotton grass fibre as sorbent for oil spills. Kaewsam *et al.*, (2008) used banana peel as sorbent in the removal of cadmium ion from aqueous solution. Kaur, (2011) used sugarcane bagasse for the removal of erythrosim B and methylene blue from aqueous solution. Mahmoud *et al.*, (2012) studied the kinetic of Ni (II) using activated clay minerals. Hasana *et al.*, (2010) investigated the selenium remediation through up-flow-fixed-bed column.

In this study, banana peel was conditioned and tested for oil uptake from produced water. Isotherms equilibria and kinetic studies on the data generated were carried out. Sorption of oil was made at various temperatures, bio-waste loading and sorption times. Characterization of the biosorbent was made using FTIR, EDS-SEM and surface area measurement using nitrogen adsorption technique by BET method.

2.0 Materials

Banana peels were collected from Muda Lawal market, Bauchi Nigeria. Crude oil was obtained from Kaduna Refinery and Petrochemical Company (KRPC), Kaduna-Nigeria. 1,1,1-tri-chloroethane was purchased from Chuzz Bond International, Jos-Nigeria. All chemicals and reagents were of analytical grade. Distilled water was obtained from Gubi Dam Water Treatment Plant Laboratory, Bauchi-Nigeria. Oven was used to dry the sorbent materials (manufactured by Regaterm, Italy). Separating funnels were used to extract out the oil from water and DR/2000 spectrophotometer (HACH, Colorado, U.S.A) was used to test the presence of oil in the extract. Hanna pH meter was used to determine the pH of the mixtures. A JJ-4 Six couplet Digital electric mixer (Search Tech Instrument, England) was used for the sorption study. Laboratory mortar and pestle were used to convert the banana peel to powder and sieves were used to classify it into different sizes (212-63 microns). Perkin Elmer Spectrum 100 FTIR spectrometer was used for the infra-red spectroscopic studies at wave numbers 4000-400 cm^{-1} . The X-ray diffractometry was done on a BRUKER AXS D8 Advance (Cu-K α radiation $\lambda K\alpha_1=1.5406\text{\AA}$) 40kV. The Hitachi X-650 Scanning Electron Microscope (Tungsten filament, EHT 20.00kV) and LEO 1450 Scanning Electron Microscope (Tungsten filament, EHT 20.00kV) were used for the SEM imaging. The chemical composition was determined using energy dispersive spectroscopy (EDS) and surface area and pore sizes were determined using TriStar 3000 V6.05 A BET equipment.

3.0 Method

3.1 Biosorbent Preparation

Banana peel was first washed with water several times and then sun-dried. The dried banana peel was ground to particle sizes between 2-3 mm and later treated with n-hexane to remove all coloured pigment in a reflux condenser. The n-hexane treated banana peel was later washed with distilled water and dried in an oven at 70°C for 24 hours. This was further crushed and sieved through 212-63 microns sieve and then stored in air tight sealed plastic containers as raw banana peel (RBP).

3.2 Characterization

The raw banana peel (RBP) biosorbent was characterized using FT-IR, SEM, and EDS. The spectrograms are presented in Figures 1, 2, and 3 respectively.

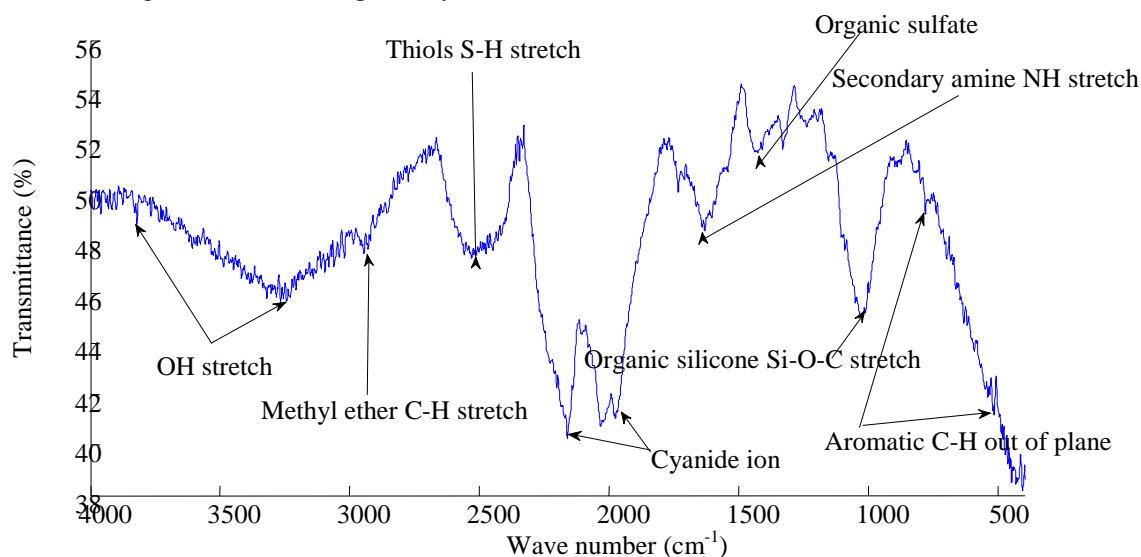


Figure 1: FT-IR spectrum of banana peel (RBP) biosorbent

From the FTIR spectra in Figure 1 above, it can be seen that many peaks exist indication of many functional groups. A shift at (Figure 1) wave number 539-800 cm^{-1} was observed and was assigned to aromatic C-H out-of plane. The shift observed at 1035 cm^{-1} was assigned to Si-O-Si silicon stretching while the absorption at 1450 cm^{-1} was assigned to organic sulfate stretch. The shift at 1600 cm^{-1} was assigned to secondary amine NH stretch. Shift at 1988-2200 cm^{-1} was as a result of cyanide ion stretching while shift at 2500 cm^{-1} was due to thiol S-H stretch. Methyl ester C-H stretch was observed at 2950 cm^{-1} . The last shift at 3250-3900 cm^{-1} was assigned to OH stretch. These assignments are in agreement with Kamsonlian et al., (2011) but slightly differ from Kaewsam et al., (2008) and Kumar et al., (2010).

Dissolved oil from the produced water polarizes in water. The charged particles initiate a reaction by opening the double and triple bonds in the banana peel structure and exchange their ions to neutralize the charges. Where the pollutants do not dissociate in solution, adsorption is by affinity of the surface to bind with the pollutant through the porous structure of the sorbent material.

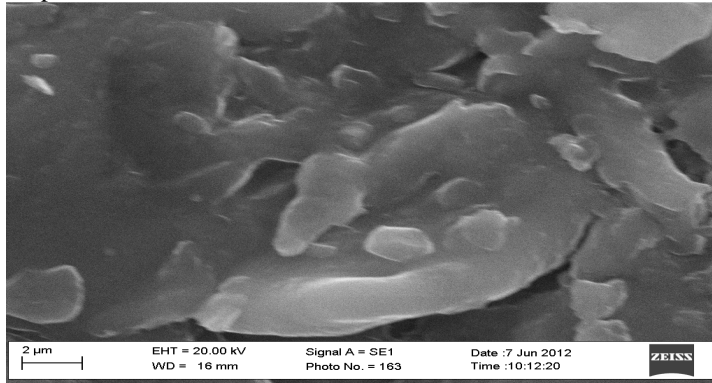


Figure 2: SEM of banana peel sample

Figure 2 shows the SEM of RBP. However, it can be said to consist of layered materials clustered together in which the sorption may take place. Particles seen on the image were measured to have equivalent spherical diameter from $37.357\text{-}179.619 \times 10^{-6}$ m and cross sectional area of $62 \times 10^{-12}\text{-}206 \times 10^{-12}$ m².

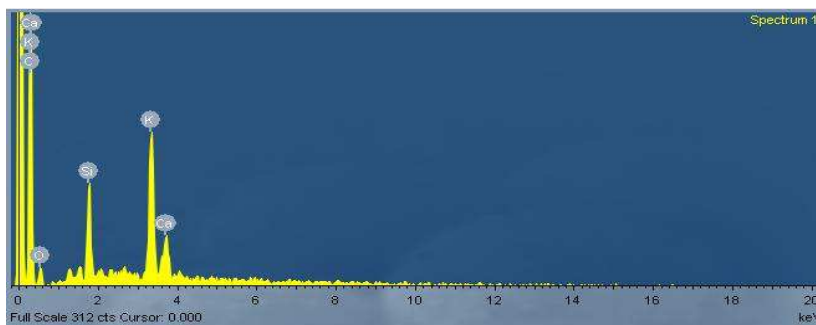


Figure 3: EDS of banana peel (RBP)

Table 1: Elemental analysis of RBP

Element	Weight, g	Atomic, %	Weight, %
C	4.65	88.52	78.41
O	0.40	5.69	6.74
Si	0.27	2.19	4.55
K	0.48	2.80	8.09
Ca	0.14	0.80	2.36
Totals	5.93	100	100

The use of peels and other bio-waste materials not only would provide less costly adsorbent or synthetic ion exchangers but is also easily available and save the environment. Banana peel has an average particle size of 0.89 nm as reported by Kamsonlian *et al.*, (2011) and a BET surface area of 1.856 m²/g. The surface area of RBP by BET and Langmuir methods were found to be 0.1135 and 0.1307 m²/g respectively. Its average pore size was determined to be 58.33421 nm while its pore volume determined to be 0.001655 cm³/g. However, the surface area did not agree with what was reported by Kamsonlian *et al.*, 2011. This may be attributed to peculiarities of the particular banana species used.

3.3 Batch adsorption experiments

The experiments were carried out by taking 300 mL of 194 mg/l produced water and different quantity of RBP in a 600 ml beaker. The contents were then agitated at 700 rpm for 30 minutes using mechanical shaker at room

temperature. The biosorbent and sorbate were separated by 63 micron sieve. Studies on the effects of agitation time, and biosorbent dose were carried out by using known amounts of biosorbents of particle size 212-63 microns. Oil solutions (300 mL) with different amounts of biosorbents were taken to study the effect of adsorbent dosage on the removal of oil. The biosorption experiments were carried out at room temperatures.

The laboratory synthesized produced water (oil-in-water mixture) was prepared by mixing crude oil with distilled water. The pH was kept constant during the experiment. The already prepared oil-water mixture was treated differently with various quantities of RBP for a period of 30 minutes and a stirring speed of 700 rpm. At the end of the treatment, RBP was removed from the oil/water mixture by passing through 63microns sieve; the residual oil in the water was determined using 1-1-1-tri-chloroethane as solvent. The extract was analyzed for oil content using HACH DR/2000 spectrophotometer at a wavelength of 450 nm. The test was repeated until optimum loading point was identified. With the optimum loading kept constant, the time was varied to determine the optimum time of the sorption study.

3.4 Adsorption isotherm

Equilibrium isotherm equations are used to describe experimental sorption data. Among several models that have been published in the literature to describe experimental data of adsorption isotherms Langmuir and Freundlich are the most frequently used models. The equation parameters and the underlying thermodynamic assumptions of these equilibrium models often provide some insight into both the sorption mechanism and the surface properties and affinity of the sorbent. The symbols and coefficients used in the equations are defined.

3.4.1. The Freundlich Isotherm

In 1906, Freundlich presented the earliest known sorption isotherm equation (Freundlich, 1906). This empirical model can be applied to non-ideal sorption on heterogeneous surfaces as well as multilayer sorption and is expressed by the following equation (Ho, *et al.*, 2001):

$$q_e = a_F C_e^{b_F} \quad (1)$$

Where, a_F Freundlich isotherm constant; C_e solution phase oil concentration at equilibrium, mg dm^{-3} ;
 The Freundlich isotherm has been derived by assuming an exponentially decaying sorption site energy distribution. It is often criticised for lacking a fundamental thermodynamic basis since it does not reduce to Henry's law at low concentrations. The linearized Freundlich equation can be used (equation 2):

$$\ln q_e = \ln a_F + b_F \ln C_e \quad (2)$$

A plot of $\ln q_e$ vs $\ln C_e$ is a straight line with slope, b_F and intercept, $\ln a_F$ (Figure 4).

3.4.2. The Langmuir Isotherm

Langmuir developed a theoretical equilibrium isotherm relating the amount of gas sorbed on a surface to the pressure of the gas (Langmuir, 1916). The Langmuir model is probably the best known and most widely applied sorption isotherm. It has produced good agreement with a wide variety of experimental data and may be represented as in equation 3 (Ho *et al.*, 2001): The Langmuir adsorption isotherm assumes that adsorption takes place at specific homogeneous sites within the adsorbent, and it has been used successfully for many monolayer adsorption processes. The linearized Langmuir can be used (equation 4):

$$q_e = \frac{k_L b C_e}{1 + k_L C_e} \quad (3)$$

$$\frac{C_e}{q_e} = \frac{1}{b k_L} + \frac{1}{b} C_e \quad (4)$$

Where, C_e is the equilibrium concentration of the sorbate (milligrams per litre), q_e is the amount of sorbate per unit mass of biosorbent (milligrams per gram), k_L is a constant representing the strength with which the solute is bound to the substrate (L/mg) and b is the adsorption capacity of the substrate (gram solute/gram adsorbent). When $\frac{C_e}{q_e}$ was plotted against C_e for RBP, a straight line with slope $\frac{1}{b}$ will be obtained and an intercept $\frac{1}{b k_L}$ while q_e is expressed as given in Equation (5).

$$q_e = \frac{V(C_i - C_e)}{m} \quad (5)$$

Where, V is the biosorption volume (litres), C_i is the initial concentration of the sorbate (milligrams/litre), and m is the mass of biosorbent (gram).

The essential characteristics of the Langmuir isotherm can be expressed in terms of a dimensionless equilibrium parameter, R_L which is defined by.

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

Where, C_o is the highest initial solute concentration, b the Langmuir's adsorption constant (L/mg). The value of R_L indicates the type of the isotherm to be either unfavorable ($R_L > 1$), linear ($R_L = 1$), favorable ($0 < R_L < 1$) or irreversible ($R_L = 0$).

4.0 Results and Discussions

4.1 Results

Tables 2 and 3 present the results obtained on biosorption of oil from water using RBP.

Table 2: Effect of RBP loading rate on oil removal from produced water

Dosage (mg)	Residual oil (C_e) (mg/L)	Oil removed (mg)	% Removal
0	194.00	0	0
10	10.66	183.34	94.51
20	8.52	185.48	95.61
30	4.26	189.74	97.80
40	2.13	191.87	98.90
50	0	194.00	100.00

Table 3: Effect of contact time on the biosorption of oil from produced water

Time (minutes)	C_e Oil left (mg/L)	Oil removed (mg/L)	% Removal
0	194.00	0	0
5	85.27	108.73	56.04
10	83.96	130.04	67.03
15	57.56	136.44	70.33
20	56.69	134.31	69.23
25	38.37	155.63	80.22
30	2.13	191.87	98.90
35	0.00	194.00	100.00
40	0.00	194.00	100.00

The linearized form of Freundlich and Langmuir isotherms (equations (2) and (5)) were used. Figures 4 and 5 in conjunction with Tables 2 and 3

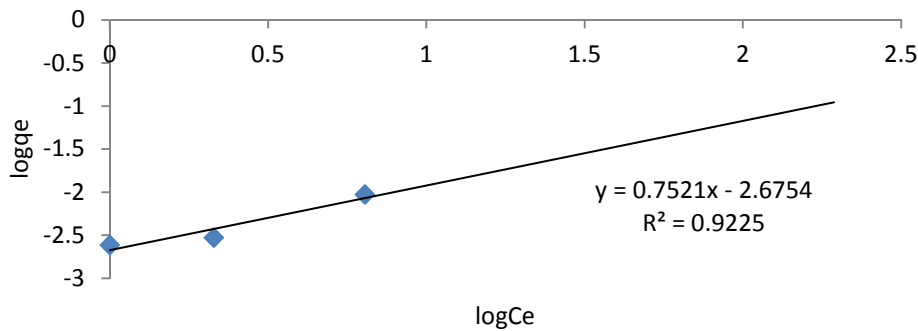


Figure 4: Freundlich Isotherm of RBP

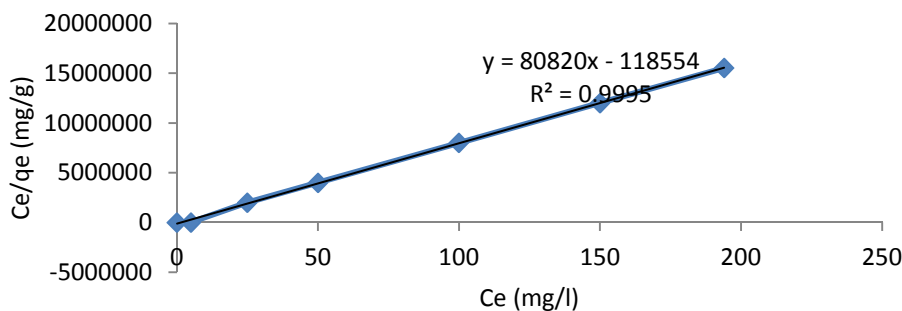


Figure 5: Langmuir plot of RBP

As can be seen from the figures, the R^2 values for the charts were satisfactory. The various constants evaluated can be seen in Table 4, from which it is clear that the sorption process is better described by Langmuir isotherm. This indicates that sorption by banana peel is mono-layer as suggested by Langmuir.

Table 4: Evaluated constants from Langmuir and Freundlich isotherms by RBP

Isotherm	R^2	B	k_L	a_F	b_F	R_L
Langmuir	0.999	1.237E-5	-6.817	-	-	0.9975
Freundlich	0.9225	-	-	0.0609	0.7521	-

R_L was evaluated from Figure 5 and the value obtained was 0.9975. Although the value of the dimensionless equilibrium parameter, R_L is satisfactorily good, the value falls within favorable range of $0 < R_L < 1$. The adsorption hence favored mono-layer as it agreed with Langmuir isotherm $R^2=0.999$.

4.2 Kinetic studies

A number of kinetic models have been proposed to elucidate the mechanism of solute adsorption. These kinetic models are useful for the design and optimization of effluent treatment process. In order to investigate the mechanism of oil biosorption by RBP, the following kinetic models were considered. Pre-equilibrium kinetic profiles were characterized in order to determine the rate limiting steps involved in the process of biosorption of oil onto RBP. The first order (Eq. (7)), Lagergren pseudo-first order (Eq. (8)) and pseudo-second order (Eq. (9)) kinetic models were applied in the biosorption of nickel on spent activated clay (Mahmoud *et al.*, 2012), reactive black 5 dye by *Aspergillus foetidus* (Patel and Suresh, 2008), biosorption of Acid Red 57 by dried *Cephalosporium aphidicola* cells (Kiran *et al.*, 2006) and biosorption of Cu^{2+} unto banana peel (Hossain *et al.*, 2012).

$$\frac{1}{q_t} = \frac{1}{q_e} + \frac{k_1}{q_e t} \quad (7)$$

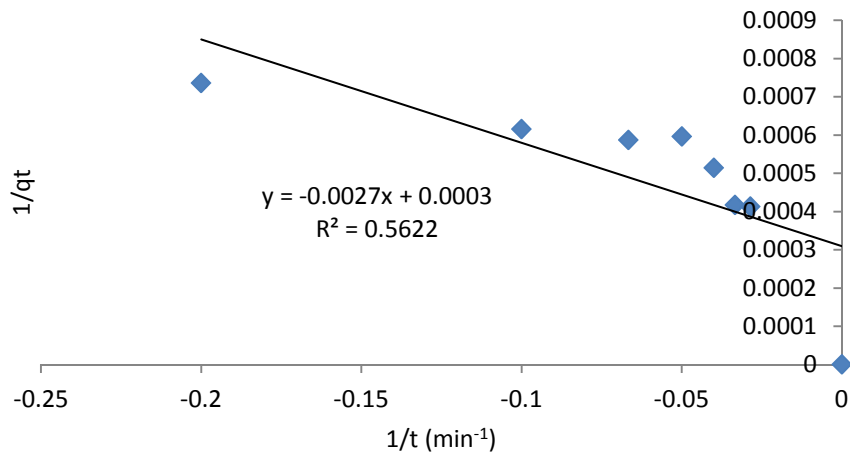


Figure 6: First order kinetic model for RBP

4.2.2 Lagergren Pseudo first order kinetic model

The integrated linear form of pseudo first order kinetic model the model proposed by Lagergren is

$$\ln(q_e - q_t) = \ln q_e - kt \quad (8)$$

Where, q_e is the amount of dye adsorbed at equilibrium (mg/g), q_t is the amount of oil adsorbed at time t (mg/g), k_1 is the first order rate constant (min^{-1}) and t is the time (min). Hence, a linear trace is expected between the two parameters $\ln(q_e - q_t)$ and t , provided the biosorption follows first order kinetics. The values of k_1 and q_e can be determined from the slope and intercept. Even though q_e and the R^2 value suggest that the biosorption data badly fitted to pseudo first order kinetics. Hence, the biosorption of oil onto RBP may not follow the pseudo first order rate expression.

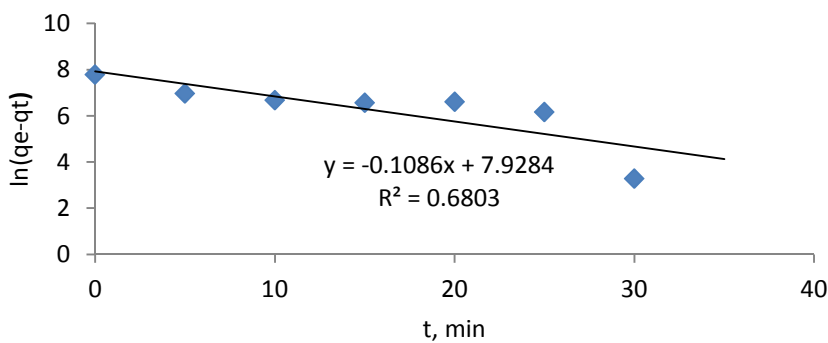


Figure 7: Pseudo-first-order kinetic model of RPB

4.2.3 Second order and pseudo second – order kinetics

The biosorption may also be described by a second order or pseudo second order kinetic model. The linearized form of the second order and pseudo second order models are:

$$\frac{1}{c_e} = k_2 t + \frac{1}{c_0} \quad (9)$$

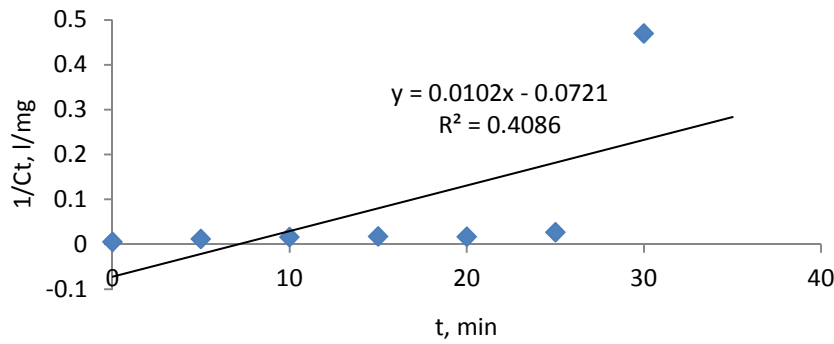


Figure 8: Second Order Kinetic Model of RBP

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \frac{1}{q_e} t \quad (10)$$

Where, k_2 is the second order rate constant (g/mg min). A plot of $1/q_e$ vs t and t/q_t vs t should be linear if the adsorption follows second order or pseudo-second order. q_e and k_2 can be calculated from the slopes and intercepts of the plots.

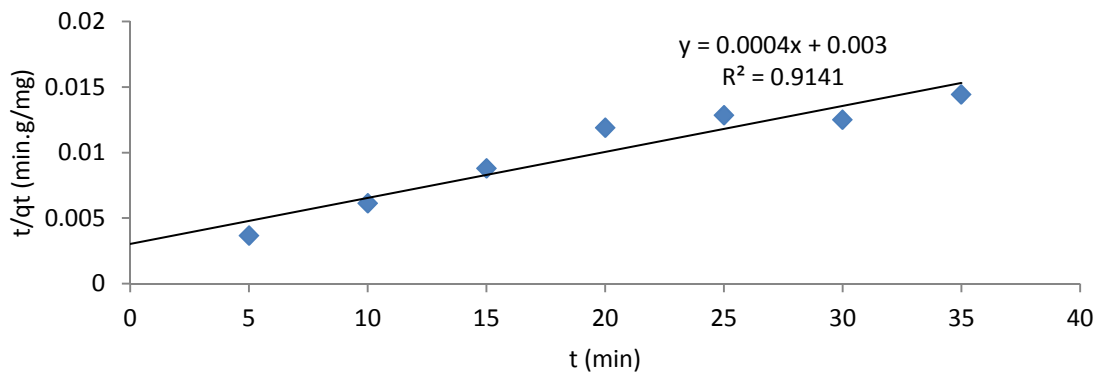


Figure 8: Pseudo-second-order Kinetic Model of RBP

4.2.4 Elovich model

The Elovich equation is mainly applicable for chemisorption process. The equation is often valid for systems in which the adsorbing surface is heterogeneous. The Elovich model is generally expressed as

$$q_t = \frac{1}{b} \ln(ab) + \frac{1}{b} \ln t \quad (11)$$

Where, a is the initial biosorption rate (mg/g min) and b is related to the extent of surface coverage and the activation energy for chemisorption (g/mg). A plot of q_t vs $\ln t$ gives a straight line with a slope of $1/b$ and an intercept of $1/b \ln(ab)$ with good correlation coefficients.

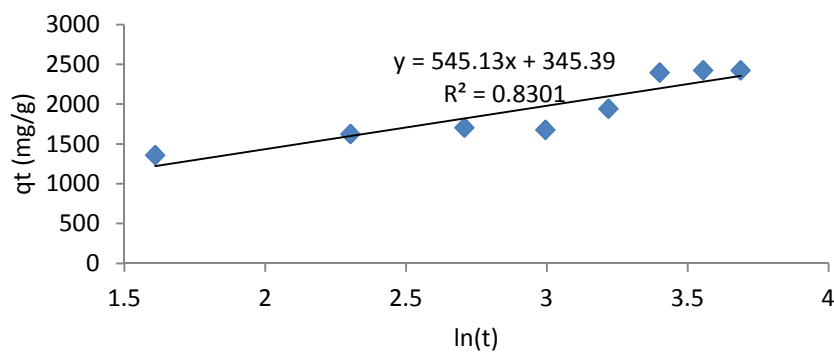


Figure 9: Elovich Kinetic Model of RBP

4.3: Effect of initial pH of water on oil removal

pH is one of the most important parameters which control the sorption process of adsorbents, functional groups and ionic state of adsorbate. The adsorption capacities/ removal efficiency of oil from water onto banana peel were strongly affected by the pH (Figure 10). The adsorption capacities/efficiency at pH 0.7, 1.1, 10.0, and 11.6 were investigated. The results were found to be 84.54, 82.99, 87.63, and 87.63% removal efficiency respectively. There was significant increased in removal efficiency from acidic to alkaline region. The increased from 82.99% to 87.63% was recorded at pH from 1.1 to 10.0. However neutral pH was not investigated. The removal efficiency (87.63%) tends to be constant at pH greater or equal to ten ($\text{pH} \geq 10$).

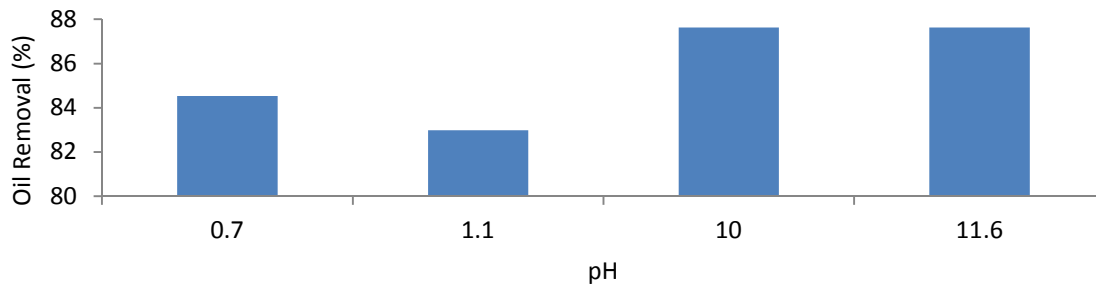


Figure 10: Effect of pH on the Biosorption of Oil using Banana Peel

4.4: Effect of initial temperature of water on oil removal

Normally temperature stimulates the molecules, functional groups and surface morphology of the adsorbent and adsorbate during adsorptions processes. To determine the thermal effects of oil adsorption onto banana peel, temperature variation experiments were conducted at 40, 50, 60 and 80°C, with an initial oil concentration 30 mg/l. The experimental data show that the equilibrium adsorptions (q_m) were increased with an increase in temperature up to 60°C when it started decreasing (Figure 11), suggesting that higher temperature helped to desorb the oil or retard the oil adsorption onto banana peel. The pattern followed by oil sorption with change in temperature can best be explained by Figure 12 and is a polynomial curve of power 3.

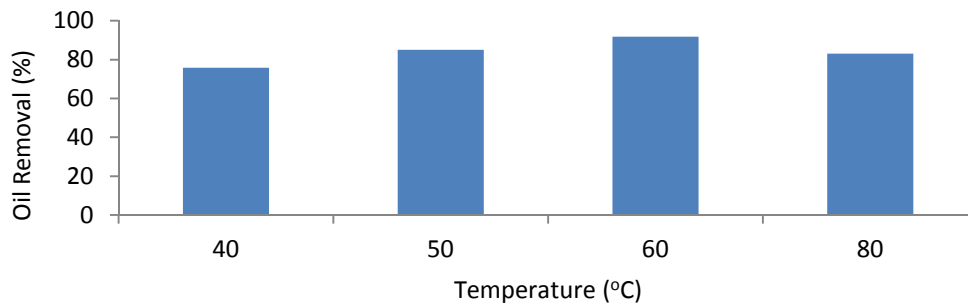


Figure 11: Effect of temperature on the Biosorption of Oil using RBP

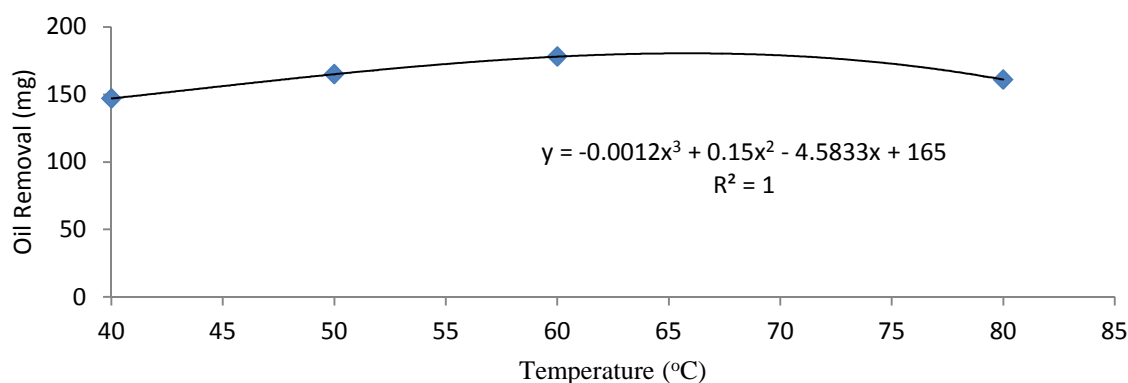


Figure 12: Biosorption of Oil on RBP with Temperature

From results of Figures 6-9, it can be deduced that oil sorption from produced water using RBP fits pseudo-second-order kinetics. Comparison of the tested kinetics and calculated constants are shown in Table 6.

Table 5: Comparison of the biosorption kinetics and evaluated constants

Kinetics	R ²	Intercept	Slope	Rate constant (k)	q _e	C _o	a	b
1 st order	0.5622	0.0003	-0.1027	-340.67	3333.33	-	-	-
Pseudo-1 st order	0.6803	7.9284	0.1086	0.1086	2774.98	-	-	-
2 nd order	0.4086	-0.6721	0.0102	0.0102	-	1.4879	-	-
Pseudo-2 nd order	0.9141	0.003	0.0004	5.333E-3	2500	-	-	-
Elovich	0.8301	345.39	545.13	-	-	-	1046.87	0.0018

5.0 Conclusion

RBP was characterized using FTIR, SEM, EDS, and BET equipment. The characterization using FTIR revealed the functional groups present on the RBP while SEM revealed the surface morphology of the sorbent. EDS revealed the elemental composition of the biosorbent to contain carbon, oxygen, silicone, potassium, and calcium. Surface area of the RBP was measured using nitrogen adsorption by BET method and found to be 1.86 m²/g with average pore size of 58.3nm. Biosorption studies with the peel showed that it can be used in the removal of oil (both dissolved and dispersed) from produced water providing almost 100% removal at an equivalent dosage representing 267 mg banana peel in produced water after 35 minutes exposure and initial oil concentration as high as 194 mg/l. Biosorption factors such as effects of loading rate, contact time, solution pH, and temperature were studied. pH and temperature effect were seen to follow a polynomial path of the third order. Several biosorption kinetic models were tested and the results showed that RBP biosorbent followed pseudo-second-order kinetics. Langmuir and Freundlich isotherms were tested with the data the results showed that Langmuir isotherm gave the best fit indicating mono-layer adsorption of oil on the RBP surface.

6.0 Acknowledgement

The authors acknowledged the financial support of the First Bank of Nigeria (Plc) through the First Bank Professorial Chair in Chemical Engineering Programme, Abubakar Tafawa Balewa University, Bauchi-Nigeria.

References

- AjayKumar, A.V., Darwish, N.A. and Hilal, N. (2009) 'Study of Various Parameters in the Biosorption of Heavy Metals on Activated Sludge', *World Applied Sciences Journal*, vol. 5, no. special, pp. 32-40.
- Angelovaa, D., Uzunovb, I., Uzunovaa, S., Gigovac, A. and Minchev, L. (2011) 'Kinetics of oil and oil products adsorption by carbonized rice husks', *Chemical Engineering Journal*, 172, pp. 306-311.
- Arunachalam, R. and Annadurai, G. (2011) 'Nano porous adsorbent from fruit peel waste for decolorization studies', *Research Journal of Environmental Sciences*, vol. 5, no. 4, pp. 366-376.

- Banerjee, S.S., Joshi, M.V. and Jayaram, R.V. (2006) 'Treatment of oil spill by sorption technique using fatty acid grafted sawdust', *Chemosphere*, vol. 64, pp. 1026-1031.
- Bhatnagar, A. and Sillanpää, M. (2010) 'Utilization of agro-industrial and municipal waste materials as potential adsorbents for water treatment—A review', *Chemical Engineering Journal*, vol. 157, p. 277–296.
- Bhatti, Y.S.a.H.N. (2011) 'Adsorptive removal of direct textile dyes by low cost agricultural waste: Application of factorial design analysis', *Chemical Engineering Journal* 167 (2011) 35–41, vol. 167, pp. 35-41.
- Calero, M., Hernaiz, F., Blazquez, G., Martin-Lara, M.A. and Tenorio, G. (2009) 'Biosorption kinetics of Cd(II), Cr(III) and Pb(II) in aqueous solution by olive stone', *Brazilian Journal of Chemical Engineering*, vol. 26, no. 02, pp. 265-273.
- Coates, J. (2000) 'Interpretation of Infrared, A practical approach', in Meyers, R.A. (ed.) *Encyclopedia of Analytical Chemistry*, Chichester: John Wiley & sons Ltd.
- Gao, J.-F., Zhang, Q., Wang, J.-H., Wu, X.-L., Wang, S.-Y. and Peng, Y.-Z. (2011) 'Contributions of functional groups and extracellular polymeric substances on the biosorption of dyes by aerobic granules', *Bioresource Technology*, vol. 805-813, p. 102.
- Hasana, S.H., Ranjana, D. and Talat, M. (2010) 'Agro-industrial waste 'wheat bran' for the biosorptive remediation of selenium through continuous up-flow fixed-bed column', *Journal of Hazardous Materials*, vol. 181, pp. 1134-1142.
- Ho, Y.S., Porter, J.F. and McKay, A.G. (2001) *equilibrium isotherm studies for the sorption of divalent metal ions onto peat: copper, nickel and lead single component systems*, september, [Online] [21 june 2012].
- Kaewsam, P., Saikaew, W. and Wongcharee, S. (2008) 'Dried biosorbent derived from banana peel: A potential biosorbent for removal of Cadmium ions from aqueous solution', The 18th Chemical Engineering & applied chemistry conference, Pattaya, Thailand, 20-27.
- Kamsonlian, S., Suresh, S., Majumder, C.B. and Chund, S. (2011) 'Characterization of orange and banana peels: Biosorption mechanisms', *Int. Journal of Science Technology Management*, vol. 2, no. 4, pp. 1-7.
- Kaur, P.S.a.H. (2011) 'Sugarcane bagasse for the removal of erythrosin B and methylene blue from aqueous waste', *Appl Water Sci* (2011) 1:135–145, vol. 1, pp. 135-145.
- Khaled, O., Mona, E.-S. and Y., E.-K.M. (2011) 'Treatment of oil–water emulsions by adsorption onto activated carbon, bentonite and deposited carbon', *Egyptian Journal of Petroleum*, vol. 20, pp. 9-15.
- Kiran, I., Akar, T., Ozcan, A.S., Ozcan, A. and Tunali, S. (2006) 'Biosorption kinetics and isotherm studies of Acid Red 57 by dried *Cephalosporium aphidicola* cells from aqueous solutions', *Biochemical Engineering Journal*, vol. 31, july, p. 197–203.
- Kumar, G.V., Ramalingam, P., Kim, M.J., Yoo, C.K. and Kumar, M.D. (2010) 'Removal of acid dye (violet 54) and adsorption kinetics model of spp. waste: A lowcost natural sorbent material', *Korean Journal of Chemical Engineering*, vol. 27, no. 5, pp. 1469-1475.
- Lim, T.-T. and Huang, X. (2007) 'Evaluation of kapok (*Ceiba pentandra* (L.) Gaertn.) as a natural', *Chemosphere*, pp. 955-963.
- Lin, J., Shang, Y., Ding, B., Yang, J., Yu, J. and Al-Deyab, S.S. (2011) 'Nanoporous polystyrene fibers for oil spill cleanup', *Marine Pollution Bulletin*, pp. 1-6.
- Liu, J., Wu, Q. and Ding, Y. (2005) 'Assembling synthesis of BaSO₄ biometric nano-superstructures through eggshell membrane template', *chemical resource Chinese U.*, vol. 21, no. 2, pp. 243-245.
- Mahmoud, N.S., Atwa, S.T., Sakr, A.K. and Geleel, M.A. (2012) 'Kinetic and Thermodynamic Study of the Adsorption of Ni (II) using Spent Activated Clay Mineral', *New York Science Journal*, vol. 5, no. 2, pp. 62-68.
- Mohammed, I.E., Gihan, F.M. and Yuh-Shan, H. (2010) 'On the use of linearized second order kinetics equation for modelling adsorption systems', *Desalination*, vol. 257, pp. 93-101.
- Muhammad, I.M., El-Nafaty, U.A. and Abdulsalam, S. (2012) 'Oil removal from produced water using banana peel', Nigerian Institute of Agricultural Engineers, Bauchi, 533-546.
- Muhammad, I.M., El-Nafaty, U.A., Abdulsalam, S. and Makarfi, a.Y.I. (2012) 'Removal of oil from produced water using eggshell', *Civil and Environmental Research*, vol. 2, no. 8, September, pp. 52-63.

- Muhammad, I., Quratulain, S., Sajjad, A., Muhammad, G.S. and Shahjahan, B..a.M.N. (2011) 'FTIR & SEM analysis of thermo-chemical fractioned sugarcane bagasse', *Turkish Journal of Biochemistry*, vol. 36, no. 4, pp. 322-328.
- Nowicki, P., Pietrzak, R. and Wachowska, H. (2010) 'Sorption properties of active carbons obtained from walnut shells by chemical and physical activation', *Catalysis Today 150 (2010) 107-114*, vol. 150, pp. 107-114.
- Othman, M.R., Akil, H.M. and Kim, J. ((2008)) 'carbonaceous Hibiscus cannabinus L. (kenaf) for treatment of oil-and-metal-contaminated water', *Bio-Chemical Engineering Journal*, vol. 41, pp. 171-174.
- Özcana, A.S., Tunalib, S., Akarb, T. and Özcana, A. (2009) 'Biosorption of lead(II) ions onto waste biomass of *Phaseolus vulgaris* L.: estimation of the equilibrium, kinetic and thermodynamic parameters', *Desalination 244 (2009) 188-198*, vol. 244, June, pp. 188-198.
- Parab, H., Sudersanan, M., Shenoy, N., Pathare, T. and Vaze, B. (2009) 'Use of Agro-Industrial Wastes for Removal of Basic Dyes from Aqueous Solutions', *Clean 2009, 37 (12), 963 – 969*, vol. 37, no. 12, pp. 963-969.
- Pasila, A. (2004) 'A biological oil adsorption filter', *Marine Pollution Bulletin*, vol. 49, pp. 1006-1-12.
- Patel, R. and Suresh, S. (2008) 'Kinetic and equilibrium studies on the biosorption of reactive black 5 dye by *Aspergillus foetidus*', *Bioresource Technology*, vol. 99, december, p. 51-58.
- Paulo, H.F.P., Herman, C.J.V., Maria, O.H.C., Daniella, R.M., Sandra, M.D.L. and Maria, L.C.P. (2011) 'Sugarcane bagasse pulping and bleaching: Thermal and chemical characterization', *Bioresources*, vol. 6, no. 3, pp. 2471-2482.
- Qiu, H., Lv, L., Pan, B., Zhang, Q., Zhang, W. and Zhang, Q.X. (2009) 'critical review in adsorption kinetic models', *Journal of Zhejiang University Science A*, vol. 10, no. 5, pp. 716-724.
- Sitea, A.D. (2001) 'Factors Affecting Sorption of Organic Compounds in Natural Sorbent/Water Systems and Sorption Coefficients for Selected Pollutants. A Review', *J. Phys. Chem. Ref. Data, Vol. 30, No. 1*, october, pp. 187-439.
- Soliman, E.M., Ahmed, S.A. and Fadl, A.A. (2011) 'Reactivity of sugar cane bagasse as a natural solid phase extractor for selective removal of Fe(III) and heavy-metal ions from natural water samples', *Arabian Journal of Chemistry (2011) 4, 63-70*, vol. 4, pp. 63-70.
- Suni, S., Kosunen, A.L., Hautala, M., Pasila, A. and Romantschuk, M. (2004) 'Use of a by-product of peat excavation, cotton grass fibre, as a sorbent for oil-spills', *Marine Pollution Bulletin 49 916-921*, vol. 49, pp. 916-921.
- T a n i a, Hubert Ribeiro., Ross, W. Smith. and Jorge Rubio (2000) 'Sorption of Oils by the Nonliving Biomass of a *Salvinia* sp.', *Environ. Sci. Technol.*, vol. 34, pp. 5201-5205.
- Venkateswaran, P. and Parimaladevi, V. (2011) 'Kinetics, Thermodynamics and Isotherm Modeling of adsorption of triphenylmethane dyes (methyl violet, malachite green and magenta II) on to fruit waste', *Journal of Applied Technology in Environmental Sanitation*, vol. 1, no. Numb e r 3, october, pp. 2 7 3 - 2 8 3.
- Vlaev, L., Petkov, P., Dimitrov, A. and Genieva, S. (2011) 'Cleanup of water polluted with crude oil or diesel fuel using rice husks ash', *Journal of the Taiwan Institute of Chemical Engineers*, vol. 42, June, p. 957-964.

This academic article was published by The International Institute for Science, Technology and Education (IISTE). The IISTE is a pioneer in the Open Access Publishing service based in the U.S. and Europe. The aim of the institute is Accelerating Global Knowledge Sharing.

More information about the publisher can be found in the IISTE's homepage:

<http://www.iiste.org>

CALL FOR PAPERS

The IISTE is currently hosting more than 30 peer-reviewed academic journals and collaborating with academic institutions around the world. There's no deadline for submission. **Prospective authors of IISTE journals can find the submission instruction on the following page:** <http://www.iiste.org/Journals/>

The IISTE editorial team promises to review and publish all the qualified submissions in a **fast** manner. All the journals articles are available online to the readers all over the world without financial, legal, or technical barriers other than those inseparable from gaining access to the internet itself. Printed version of the journals is also available upon request of readers and authors.

IISTE Knowledge Sharing Partners

EBSCO, Index Copernicus, Ulrich's Periodicals Directory, JournalTOCS, PKP Open Archives Harvester, Bielefeld Academic Search Engine, Elektronische Zeitschriftenbibliothek EZB, Open J-Gate, OCLC WorldCat, Universe Digital Library, NewJour, Google Scholar

