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Oil removal from crude oil polluted water using banana peel as sorbent in a packed column

U.M. Aliyu
Chemical Engineering Department, Faculty of Engineering and Engineering Technology, Abubakar Tafawa Balewa University, Bauchi-Nigeria
Email: usmanaliyumohammed@gmail.com

U.A. El-Nafaty
Chemical Engineering Department, Faculty of Engineering and Engineering Technology, Abubakar Tafawa Balewa University, Bauchi-Nigeria
Email: elnafaty@gmail.com

I.M. Muhammad (Corresponding Author)
Chemical Engineering Department, Faculty of Engineering and Engineering Technology, Abubakar Tafawa Balewa University, Bauchi-Nigeria
Email: idrismisau@gmail.com

Abstract
A column study was conducted to evaluate efficiency of banana peel as sorbent in the removal of oil from crude oil polluted water. The study was carried out in a packed continuous column with initial oil concentration of 200 mg/L for 6 h. The result showed that increasing the bed height of the packing from 5-30 cm led to an increase in percentage removal of the oil from 87.82 - 97.45% at constant contact time of 20 min and flow rate of 21.6 ml/min (R^2=0.9951). This study identifies the banana peel waste as a suitable sorbent to be utilized for continuous remediation of oil from oil polluted water. The maximum uptake of 171.474mg oil was recorded at 25cm bed height, 21.6 mL/min flow rate. The BDST model was used to predict the relationship between service time and bed height, which is essential in column process design. The experimental data gave a fit to the BDST model with R^2=0.9929.
Keywords: (banana peel, packed column, sorbent, crude oil, polluted water)

1.0 Introduction

The amounts and types of oily wastes discharged from various industries vary considerably. In the petroleum industry, mixtures of oil and water are encountered in various stages of production, transport, storage and the refining of petroleum. Such mixtures are sometimes encountered in other industries that use or handle oils. Pumps, valves and other blending devices produce a mixing of the two phases and the formation of oil in water and water in oil emulsions. These emulsions sometimes escape into the environment in effluent streams. It is generally quite difficult to separate oils in these emulsions from the accompanying water (RIBEIRO, et al., 2003).

One of the most important cases of marine pollution is the oil pollution caused both accidentally and by routine ship operations. During the last decade approximately four oil spills over 700 tones occurred and 24,000 tons of oil were spilled by tankers annually worldwide (Karakasi & Moutsatsou, 2010). Immediate action for the prevention of oil pollution is required and to this direction several oil spill clean-up techniques have been developed. These include the use of booms and skimmers, oil pumping, in-situ burning, bioremediation, use of chemical agents, such as dispersants, solidifiers and sorbents (Karakasi & Moutsatsou, 2010). The use of sorbents is of great interest, as it allows the collection and complete removal of oil, by achieving a change from liquid to semi-solid phase. The efficiency of an oil sorbent material is determined by properties, such as hydrophobicity, oleophilicity, high uptake capacity, high rate of uptake, retention over time, oil recovery, reusability and biodegradability. The sorbent materials in use for oil spill clean-up include organic natural ones, such as high calcium fly ash (Karakasi & Moutsatsou, 2010), raw eggshell (Muhammad, et al., 2012), rice husk ash (Vlaev, et al., 2011), banana pseudo-stem fibers (Husin, et al., 2011), carbonized rice husks (Kumagai, et al., 2007), peanut hull ash (Tse-Li & Chun, 2009), activated carbon, bentonite, and deposited carbon (Okiel, et al., 2011), commercial resin in packed bed (Maiti, et al., 2011), oil removal using bio-materials (Srinivasan & Viraraghavan, 2010), walnut shell media (Srinivasan & Viraraghavan, 2008), fatty acid modified banana trunk fibers (Sathasivam & Haris, 2010), agricultural waste barley straw (Ibrahim, et al., 2010), banana peel in batch study (El-Nafaty, et al., 2013) have already been investigated.

In this paper, we report the use of banana peel in a packed column for removal of oil from crude oil contaminated water.

2.0 Materials

Banana peel was obtained from fruit market in Muda Lawal market, Bauchi State, Nigeria. Crude oil was obtained from Kaduna Refinery and Petrochemical Company, Kaduna-Nigeria. tri-chloro-ethane was purchased from Chuzz Bond International, Jos-Nigeria. All chemicals/reagents were of analytical grade. Distilled water was produced in Gubi Dam Water Treatment Plant Laboratory, Bauchi-Nigeria. Oven (manufactured by Regaterm, Italy) was used to dry the sorbent materials. Separating funnels were used to extract the oil from water and DR/2000 spectrophotometer (HACH, Colorado, U.S.A) was used to quantify the oil content in the extract.

3.0 Methods

3.1 Preparation of banana peel

The banana peel obtained was washed with ordinary water to remove suspended particles and then sun dried. The dried material was then washed severally with distilled water to remove water soluble materials and later dried in an oven at temperature of 105^0C until constant weight. The peel was removed and allowed to cool down to ambient temperature. It was later crushed using a laboratory mortar and pestle to particle sizes between 2-3 mm diameters and stored in a plastic container.

3.2 Synthesis of oil polluted water

The oil polluted water was synthesized in the laboratory by mixing 25liters of distilled water with 5g of crude oil and shaken vigorously and was stored in a 25L keg for sorption study.

3.3 Experimental procedure

The glass column was clamped vertically on the ply wood and a meter rule was also placed vertically beside the column and clamped as shown in Fig. 1. The base of the meter rule and the column were at the same level. A perforated cork was inserted at the bottom of the column. A plastic container containing the produced water was placed above with a rubber tube connected to a valve and dropped into the column continuously. A beaker was placed below the column to collect the treated water.

The column was filled with the processed banana peel to a height of 5cm. The valve was slightly opened and the oil polluted water allowed to drop into the column at a constant flow such that the oil in water mixture will have a proper contact time with the packed sorbent before passing through the bed. The treated water was collected using a beaker below the column. The flow rate at each height was determined by the volume collected in the beaker and the time taken (started immediately the water began to drop in the beaker) to fill it. The experiment was repeated for bed height of 10,15,20,25, and 30cm respectively. Each of the samples was collected separately and labeled properly in a sample bottle.

Figure 1: column experimental set up

3.4 Sample analysis

350ml of the treated water was taken from the each sample and mixed with 35ml of 1, 1, 1-trichoroethane in a separating funnel. The mixture was shaken vigorously for 1min and then allowed to settle for 10min, thereby forming two immiscible layers. 25ml of the lower layer was separated and analyzed using DR2000 spectrophotometer. The above procedure was repeated for each of the samples from the respective heights and the values recorded.

4.0 Results and discussion

The result of the effect bed height on oil sorption using banana peel is given in Table 1 and effect of bed depth service time (BDST) is presented in Table 2. All experiment was made at constant time of 20min, pH 8.3 and a flow rate of 0.19 mL/sec.

Table 1: Effect of bed height on oil sorption using banana peel (contact time: 20 min)

Bed height (cm)	Residual oil C_e(mg/l)	% oil removal
0	176	0
5	21.43	87.82
10	17.25	90.20
15	13.07	92.57
20	7.82	95.56
25	4.53	97.27
30	4.49	97.45

Table 2: Effect of Bed Depth Service Time on oil sorption

Bed height (cm)	Service time (min)
5	16.20
10	28.60
15	37.30
20	49.50
25	60.10
30	76.30

5.0 Discussion of results

5.1 Bed depth service time

Experimental evaluation of the performance of a fixed-bed column in sorption is generally possible only with small laboratory columns. The data collected during laboratory studies can very well be utilized for predicting and evaluating the performance of practical size columns by applying suitable mathematical models developed for such purposes. Several models have been reported for predicting the breakthrough performance in fixed-bed sorption. Among various design approaches, bed depth service time (BDST) approach based on Bohart and Adams equation is widely used. This approach, is based on surface reaction rate theory, and it gives an idea of the efficiency of the column under constant operating conditions for achieving a desired breakthrough level. In the fixed-bed systems, the main design criterion is to predict how long the adsorbent material will be able to sustain removing a specified amount of impurity from solution before regeneration is needed. This period of time is called the service time of the bed. BDST is a simple model for predicting the relationship between bed height (Z) and service time (t) in terms of process concentrations and adsorption parameters. Hutchins proposed a linear relationship between bed height and service time given by the equation below:

$$t = \frac{N_o}{C_o u} - \frac{1}{k_a c_o}\left(\frac{Co}{Cb} - 1\right) \qquad (1)$$

where C_o is the initial oil concentration (mg/L), C_b is the breakthrough oil concentration (mg/L), u is the linear velocity (cm/min), N_o is the sorption capacity of bed (mg/L), k_a is the rate constant in BDST model (L/mg/min), t is the time (min) and Z is the bed height (cm) of the column. Eq. (1) can be rewritten in the form of a straight line as presented in Eq. 2.

$$t = aZ - b \qquad (2)$$

where,

a = $slope = \frac{N_o}{C_o u}$ and

$$b = intercept = \frac{1}{k_a C_o} In\left(\frac{C_o}{C_b} - 1\right)$$

The critical bed depth (Z_o) is the theoretical depth of the sorbent sufficient to ensure that the outlet solute concentration does not exceed the breakthrough concentration, C_b, value (4.53mg/L in the present study) at time t=0. Z_o can be calculated by setting t = 0 and solving Eq. (2) for Z yields Eq. 3.

$$Z_o = \frac{u}{k_a N_o} In\left(\frac{C_o}{C_b} - 1\right) \qquad (3)$$

Table 2 shows the variation in height against time. For each height, the service time for the collection of 350mL of the treated water was taken. For the modeling of column data a more recent and widely used BDST model was used. For this purpose the service time of the column corresponding to bed heights 5, 10, 15, 20, 25 and 30cm at flow rate of 21.6 mL/min. A graph is plotted against service time and bed depth is presented in Fig. 3. BDST plot and their corresponding values of correlation coefficient (R^2=0.9929) are given in Fig. 2. From the slope and intercept of these fitted BDST equations, the BDST parameters sorption rate constant k_a, sorption capacity (N_o) and critical bed depth (Z_o) were calculated as below. The values of the correlation coefficient (R^2=0.9929) showed that the variation of the service time with bed depth is highly linear for all the systems, thus, indicating the validity of the BDST model when applied to the continuous column studies.

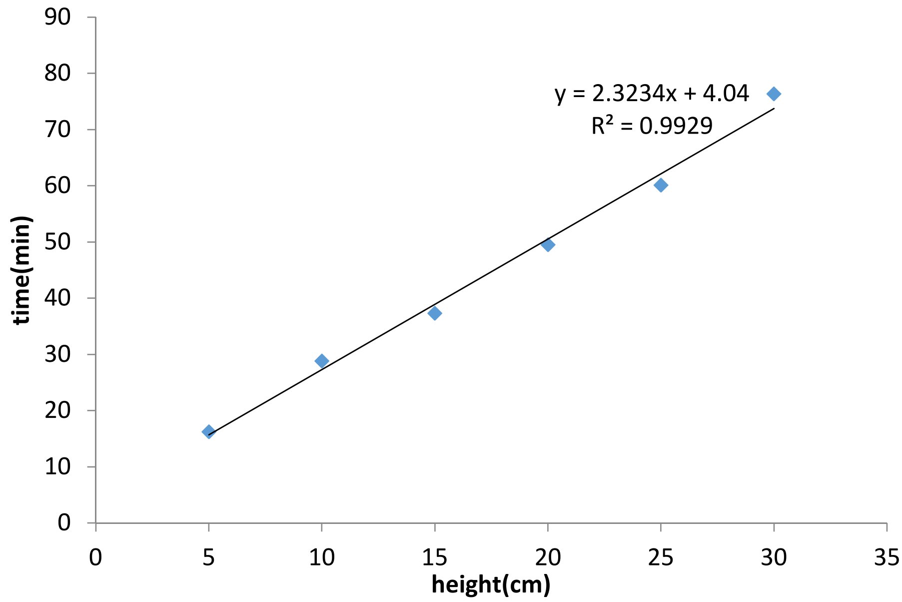

Figure 2: Effect of time against bed height

5.2 Effect of bed height on oil removal

The breakthrough curves obtained for oil sorption onto banana peel at different bed heights (5, 15, 20, 25 and 30 cm), at a constant flow rate of 21.6 mL/min and pH of 8.3 are shown in Fig 3. The results indicated that when the bed height increased from 5 to 10 cm there was an increase in the volume of water treated. This can be attributed to the fact that when there was an increase in bed height, the axial dispersion got decreased in the mass transfer and as a result the diffusion of the oil into the sorbent got increased. Thus, the solute got enough time to get diffuse into the whole of the sorbent mass, staying for more time into the column and treating more volume of effluent. Further, it was also observed that the sorption capacity as well as percentage removal efficiency of banana peel for the oil increased with the increase in bed height. The optimum uptake, which was 171.47mg/L, was found at bed depth 25 cm. The increase in the uptake of oil with the bed height was due to an increase in the sorbent doses in larger beds which provided more sorption sites for the oil removal. Increasing the bed height to 30 cm gave an insignificant change in the amount of oil removed with a 97.45% oil removal. The plot of bed height against percentage oil removal is presented in Fig 3. Sorbent particle sizes less than 2 mm were tried but it tends to clog preventing penetration through the bed.

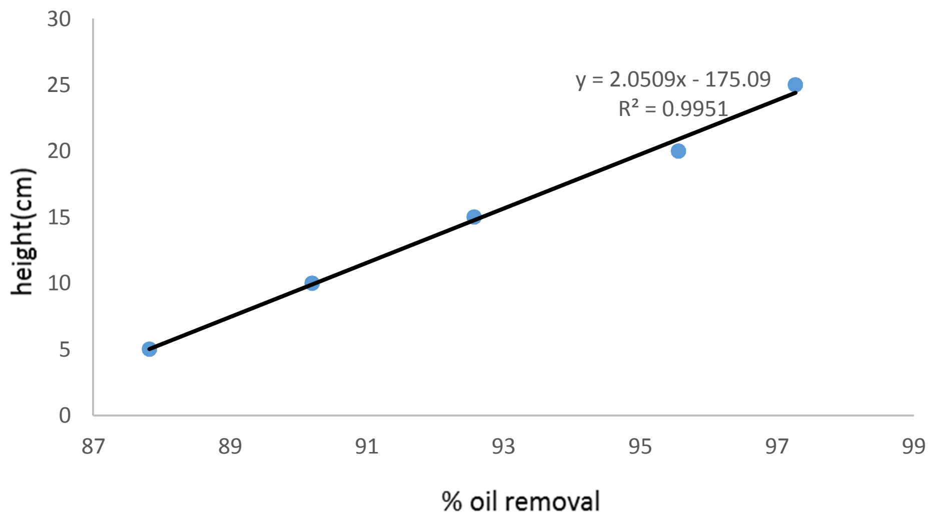

Figure 3: Effect of bed hieght on oil removal

6.0 Conclusion

From the results obtained in this work the following conclusions could be drawn**;**

1. Increasing the bed height of the packing from 5-30 cm leads to increase in percentage removal of the oil from 87.82 - 97.45% at constant contact time of 20 min and flow rate of 21.6 mL/min respectively.
2. Banana peel is readily available low cost sorbent which can be used to remove oil from oil polluted water.
3. This study identifies the banana peel waste as a suitable sorbent to be utilized for continuous remediation of oil from oil polluted water. The sorption of oil is strongly dependent on the bed height and flow rate. An increase in bed height resulted in improved sorption performance. The maximum uptake of 171.474mg for of oil was recorded at 25cm bed height, 21.6 mL/min flow rate.
4. The BDST model was used to predict the relationship between service time and bed height, which is essential in column process design. The experimental data gave a fit to the BDST model.

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