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Examining the effect of temperature on crude oil contaminated water treated using bio-adsorbent in a packed bed

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ABSTRACT

The study examined the impact of temperature on the performance of the bio-adsorbents in a packed bed unit for the mitigation (reduction or removal) of total petroleum hydrocarbon (TPH) from the fresh water medium using agro-based fiber, which was prepared by subjecting the agro materials to sun and room drying before grinding into powder form of different particles. The bio-adsorbents used are plantain stem fiber, banana stem fiber, and palm fruit fiber. The investigation was performed at packed bed unit adsorption of o.2m3/sec of flow rate, constant packed bed unit height of 27cm. The impact of temperature on changes in physiochemical characteristics, microbial count, mitigation of total petroleum hydrocarbons (TPH), resident time, and pace of TPH remediation was observed. However, the equilibrium uptake and rate constants of Yoon-Nelson (KYN), Thomas (KTh), and Bohart-Adams (KAB) were determined using the adsorption parameters of the Yoon-Nelson, Adams-Bohart, and Thomas models. In fact, changes in KYN, KTh, KAB, and q0 were discovered, and correlation coefficients between these variables were found to be between 0.9165 and 0.9999. Performance efficiencies of up to 99.99% were displayed in operating temperature breakthrough plots, which illustrate how temperature influences adsorbent performance. Each packed bed unit's fluctuation in Total Petroleum Hydrocarbon (TPH) concentration as well as the physicochemical characteristics of the pollutants were observed before and after treatment. As polluted water medium travels through each of the packed bed units, the TPH concentration decreases, and this decline is regulated by temperature fluctuation.

Keywords: Contamination, water treatment, packed bed, crude oil, temperature

1. INTRODUCTION

The amount of oil and its major impact on the environment, as well as the level of treatment prior to charging the environment, determine the degree of pollution or contamination (Chen et al., 2011). A high concentration of pollutants or toxins in a particular location was found to have an immediate negative impact on the lives

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of flora and fauna as well as a degree of ecosystem deterioration (Coiwell et al., 2011). The Niger Delta region of Nigeria is the country's center for petroleum production and processing, according to research done by the World Bank in 1995. It should be emphasized that the Niger Delta, which spans more than 20,000 km in southern Nigeria, is likewise regarded as one of the biggest wet lands. It is regarded as having the most natural resources in Nigeria, including significant oil and gas reserves, broad forested areas suited for agriculture, and a wealth of water resources for fishing and other domestic and industrial uses.

Despite having abundant natural and human resources, the Rivers State region has untapped potential for sustainable development, and its future is threatened by a variety of environmental issues linked to various discharges within the state from the industrial activities occurring in the region or state that are currently endangering the environment with sawdust (Mohammed et al., 2020). Microorganisms are found everywhere in nature, according to research by numerous scientific organizations, and their presence greatly aids in resolving environmental issues. In this instance, the contaminants are used as some of the food, and the bioreaction of the process results in products that are friendly to the environment, such as carbon dioxide (CO2), water H2O, and methane (CH4), as well as heat releases on the process, biomass concentration, or an increase in the growth rate of the microorganisms involved in the process's degradation reaction (Reddy and Chinthamreddy, 1999).

2. MATERIALS AND METHODS

Equipment

The following equipment were used for purpose of this research work.

Equipment/Apparatus

Conductivity gauge, Glass beakers, 9100 ml volumetric flask containers made of polythene Spectrophotometer for atomic absorption (AAB), unit for distilling water, Beakers, pipettes with gradations, Polyethylene top and polypropylene sample container Refrigerator, hot plate or mantle for heating fume cabinet, category funnel, Paper for medium-speed filters, valve, connections made of PVC pipe, line 1 of the control wire for the heater, temperature gauge, stuffed bed sheet, line for recalculation, second control wire from the pump, Pump, Unit Tank, Digital or Electronic Pressure Gauge in PSI, Flex Connector, (Temperature Controlled) heater, a packed bed frame, nut and bolt pump for circulation, Filter material and the temperature control box on the control panel.

Methods

Sample Collection

For the purpose of this study, crude oil samples were obtained from Rivers State University Port Harcourt's Chemical/Petrochemical Laboratory. Water samples were also obtained from the Orashi River, which is located on East-West Road in Ahoada Town's Ahoada East Local Government Area. The water samples were preserved at 4oC with ice blocks to prevent changes in composition, and they were transported in the Department of Chemical/Petrochemical Engineering laboratory.

Microbial Isolation and Identification

The microorganisms present in crude oil and water sample was isolated and identified and the medium used for the enumeration and isolation of aerobic heterotrophic bacteria for the isolation of non-fastidious bacteria.

Physiochemical Parameters

Determination pH of Fresh Water and Contaminated Water

The pH meter and electrodes were set up according to the manufacturer’s instructions

The meter was calibrated against two buffer solutions. Either buffers pH 7.0 and 4.0 or pH 7.0 and 10.0

The expected pH was highlighted with a range of the samples to be analysed

The pH meter calibration was performed based on the manufacturer’s specification.

pH for Contaminated Water (Waste Water)

Water and waste water

The pH meter and electrodes were set up according to the manufacturer’s instructions

On completion of the calibration run, the following procedures were done such as rinsing the electrodes thoroughly with distilled water, and blot dry with soft tissue paper

The electrodes were inserted to the sample
The pH and temperature values were recorded after 1.20 seconds

Sample Preparation

The majority of samples are mounted tightly on a specimen holder known as a specimen stub and must all be the proper size to fit in the specimen chamber. Any portion of a 6-inch (15-cm) semiconductor wafer can be examined using a variety of SEM models, and some of them can tilt an object that size to 450 degrees (Reed et al., 1995). Using either low-vacuum sputter coating or high-vacuum evaporation, samples are covered with a platinum coating of an electrically conducting substance. The specimen is placed in a chamber with a relatively high pressure, short working distance, and differential pumping of the electron optical column to maintain a sufficiently low vacuum at the electron gun.

In the ESEM, the high-pressure area surrounding the sample neutralizes charge and amplifies the secondary electron signal. Due to the field emission guns' (FEG) ability to produce brilliant primary electrons and small spots even at low accelerating potentials, low-voltage SEM is commonly performed in a FEG-SEM (Sez and Ruttman, 1993; Shapiro and Probstein, 1993). When doing quantitative X-ray microanalysis or imaging in backscattered electrons, embedding in a resin and further polishing to a mirror-like finish can be used for both biological and material specimens (Sharifpour et al., 2020).

Flow Diagram of Treatment Process

Figure 1 demonstrate the treatment plant of crude oil contaminated water using bio-adsorbent. Detail description of the treatment unit is well labelled as the process was discussed earlier.

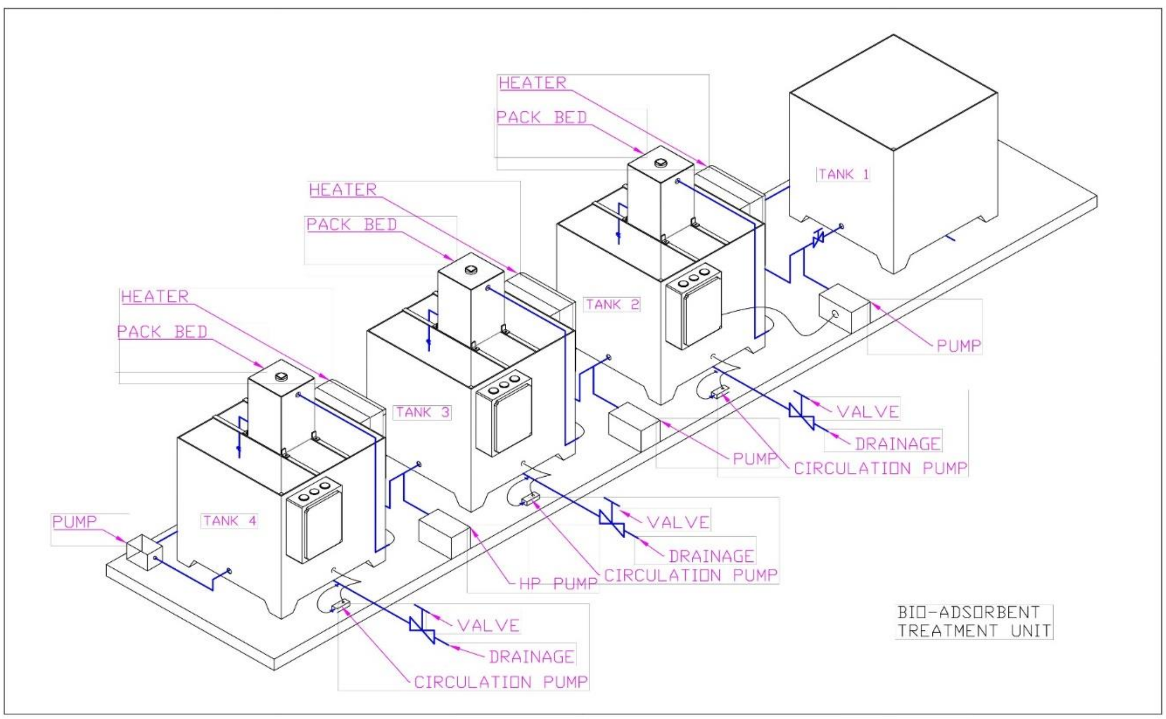

Figure 1 Flow Diagram of the Treatment Plant

The connection for polluted water inlets and outlets, valves, PVC pipe as connectors, control wire line to the heaters, temperature probe, and the lid for the packed bed unit are some more crucial parts as shown in (Figure 1). Figure 1 illustrates a detailed explanation of the flow diagram for the evaluation of temperature influence on bio-adsorbent for packed bed unit treatment of crude oil polluted water media. The dirty water (effluent) is added to tank 1 of the unit before being allowed to pass through a 2" PVC pipe at a volumetric flow rate of 0.2 m3/s. The temperature of the heating unit, which was maintained constant at 150C, 300C, 450C, 600C, 750C, 900C, 1050C, and 1200C, is controlled by the outflow value from unit tank 1. A sample was taken from the outlet point in the tank designated as the second units after the effluent had passed through the first packed bed unit.

The packed bed units 1, 2, and 3 were each filled with the same bio-adsorbent and the contaminants were allowed to pass through the heater 1 as well as the packed bed unit 1. The resident time was monitored. The treatment is carried out batch-wise, and the manufactured plants were linked in series. Additionally, the exit product serves as the intake feed for the ongoing treatment of contaminants in the next packed bed unit 2. The packed bed units 1, 2 and 3 were filled with bio adsorbent mixture of particle size of 50μm, 150μm and 200μm in the ratio of 1:1:1. The effluent from unit 1 was analysed in terms of physicochemical parameters, microbial activities and effluent concentration and the obtained data was compared with the World Health Organization standard, especially for the physiochemical parameters.

This procedure was repeated for plant 3 unit. The outlet product was examined, and the process treatment plant was designed so that, should it be determined that the concentration of the effluent treatment after passing through plant 3 unit does not meet the required specification, the end product can be sent back to the initial inlet flow line of the plant 1 unit for additional treatment. In fact, after washing and flashing the flow line and the unit components of the treatment plant, it is necessary to further re-treat the initial end product by reintroducing additional bio-adsorbent into the processing plant (Sturini et al., 2015). The various bio-adsorbents used for this investigation are plantain stem fibre, banana stem fibre and palm fruit fibre, which was subjected into sun and room dried.

The bio-adsorbent was crushed into different particle size and sacred to obtain particle size of 50μm, 150μm and 200μm for both sun dried and room dried of each bio-adsorbent. As described above equal volume and mass of each particle size of the bio-adsorbent was measured and recorded, before introducing it into each of the packed bed unit. This process was done at different operating temperatures as discuss early and samples were taken for analyzers as well as repeated for each of the bio-adsorbent and the data obtained were compared for the purpose of the determination of the most effective bio-adsorbent for treatment of contaminated water with crude oil and the best operating temperature for optimum removal of the contaminants by the bio-adsorbent (Taheran et al., 2018; Teas et al., 2001).

Adsorption Modeling

The following models were employed in this research as demonstrated.

Thomas model for column adsorption

The Thomas model was demonstrated in terms of Nonlinear, linear, plot method.

For Nonlinear

$$\frac{C_t}{C_o} = \frac{1}{1+\exp\left(\frac{K_{Th}}{Q}\left(q_T\, x - C_0 V_{eff}\right)\right)} \tag{1}$$

For Nonlinear

$$In\left[\frac{C_0}{C_t} - 1\right] = \left[\frac{K_{Th} q_0 X}{Q}\right] - K_{Th} C_0 t \tag{2}$$

For plot method

$$In\left[\frac{C_0}{C_1} - 1\right] v_s\ t \tag{3}$$

where slope = - $K_{Th} C_0$

and intercept = $\frac{K_{Th} q_0 X}{Q}$

Adam – Bohart model for column adsorption

The Adam-Bohart model was illustrated in terms of non – linear, linear and plot method (Ekperi and Okogbule-Wonodi, 2023).

None-Linear

$$T = \frac{N_0 \tau}{C_0 V} - \left[\frac{In\left(\frac{C_0}{C_t} - 1\right)}{C_0 K_{AB}}\right] \tag{4}$$

Linear

$$In\left(\frac{C_t}{C_0}\right) = K_{AB}\ C_0 t - \frac{K_{AB} N_0 \tau}{F} \tag{5}$$

where Slope = $K_{AB}C_0$
curve = - $\frac{K_{AB}N_0\tau}{F}$

Yoon-Nelson Model
Non-Linear

$$\frac{C_t}{C_0} = [1 + e\,K_{Th}\,(\tau - t)]\text{-}1 \quad (6)$$

Linear

$$In\left[\frac{C_t}{C_0 - C_t}\right] = K_{YN}t - \tau K_{YN} \quad (7)$$

where
slope = K_{YN}
Curve = τK_{YN}
For plot method

$$In\left[\frac{C_t}{C_0 - C_t}\right] v_s\, t \quad (8)$$

where;

C_0 denotes initial concentration of TPH
C_t denotes concentration of TPH at time.
F denotes linear velocity calculated by dividing the flow rate by the column section area (cm/min).
K_{AB} denotes Bohart – Adams rate constant (L/mg min)
K_{Th} denotes Thomas rate constant
K_{YN} denotes yoon – Nelson rate constant (min-1)
N_0 denotes adsorption capacity of the adsorbent (mg/L).
Q denotes the flow rate (ML/min).
q_0 denotes the equilibrium uptake per g of the adsorbent maximum sorption capacity
t denote the flow time (mins)
x denotes the mass of the used adsorbent in g
z denotes the bed depth of the column (cm)
T denotes the time required for 50% adsorbate breakthrough
C_0 initial concentration of TPH =
C_t concentration of TPH at time =
F Linear velocity calculated by dividing the flow rate by the column section areas (cm/min).
K_{AB} Bohart – Adamas rate constant (L/mg min).
K_{Th} Thomas rate constant
K_{YN} Yoon – Nelson rate constant (Min-1)
N_0 adsorption capacity of the adsorbent (mg/L)
Q flow rate (ML/min) = $0.2m^2/_{sec}$ =
q_0 equilibrium uptake per g of the adsorbent maximum sorption capacity =
t flow time (min) = 10 to 60min
x mass of the used adsorbent in g = 1500g = 1.5kg
z bed dept of the column (cm) = 45cm = 0.45m

3. RESULTS AND DISCUSSIONS

The comparison of the percentage of TPH (contaminants) removed in three packed beds connected in series is shown in (Figure 2). The operation was batch-wise, and the effect of temperature on the pollutant reduction was looked into. The packed bed 1 shows the highest decrease of contaminants, followed by the packed bed 2, and then the packed bed 3. Sun-dried plantain stem fiber has the ability to act as a bio-adsorbent for the treatment of contaminated water or for the efficient removal of impurities. As a result, the outcome shows that packed bed 1 performs better than packed bed 2 and packed bed 3, respectively. For packed beds 1, 2, and 3, the maximum pollutants were removed at temperatures of 45°C (63.21%), 90°C (37.83%), and 60°C (55.34%).

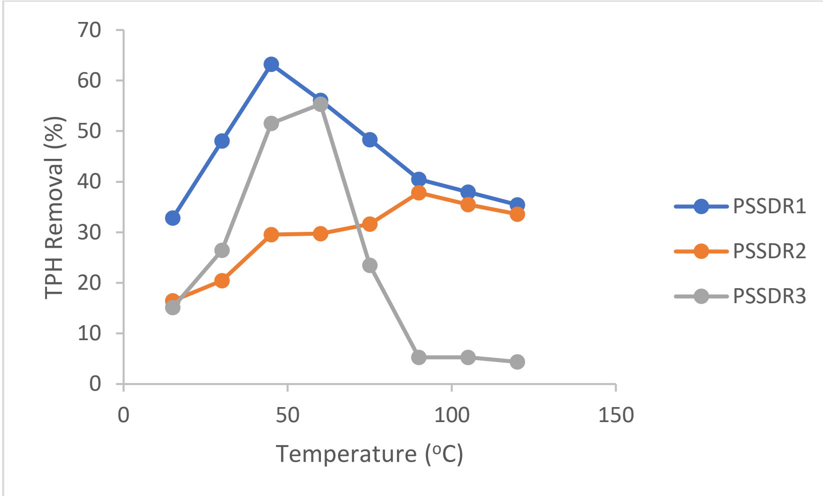

Figure 2 Comparison of Percentage Removal of TPH (Contaminants) in the Three packed Bed versus Temperature Effect for Plantain Stem Sun Dried as Bio-adsorbent

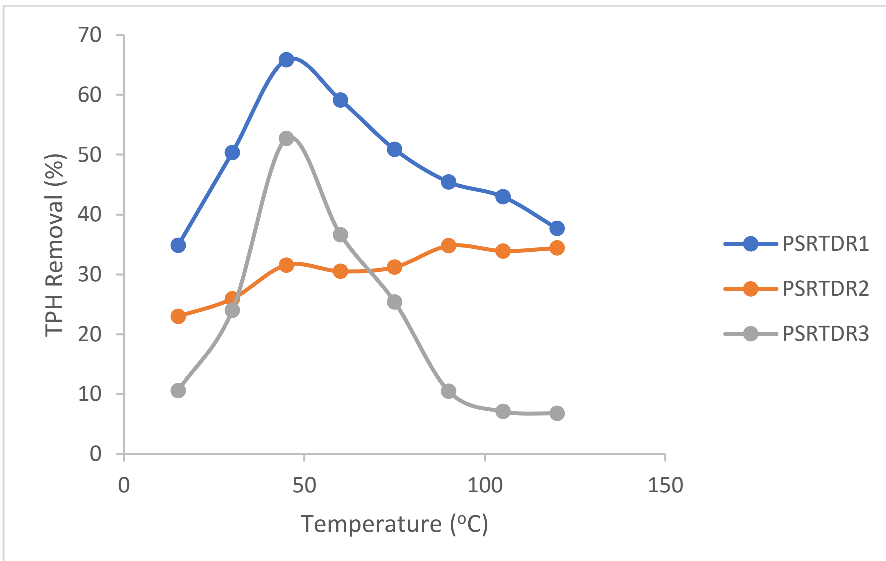

Figure 3 Comparison of Percentage Removal of TPH (Contaminants) in the Three packed Bed versus Temperature Effect for Plantain Stem Sun Dried as Bio-adsorbent

Figure 3 compares the rate of pollutant reduction in each packed bed in terms of the percentage of contaminants that were removed in the operation as a function of temperature. High levels of pollutants were reduced in packed bed 1 before being reduced in packed bed 2, and then in packed bed 3. However, the operating temperature had an impact on the variation in contaminants (TPH) elimination. The first treatment increased decrease up to 65.83% maximum at 45°C for packed bed 1, 34.77% maximum at 90°C for packed bed 2, and 52.69% maximum at 45°C for plantain steam fiber of room dried medium.

Figure 4 compares the percentage reduction caused by the temperature effect by a bio-adsorbent employing palm fruit fiber of a sun-dried medium. The highest reduction in each packed bed was recorded as 57.32% (at 45°C) for packed bed 1, 34.71% (at 105°C) for packed bed 2, and 39.24% (at 45°C) for packed bed 3. However, the reduction in contaminated water medium (effluent) by the bio-adsorbent was explored. In fact, a large portion of the pollutants are eliminated in packed 1, then packed 2, and finally packed bed 3.

Figure 5 compares the reduction of pollutants using room-dried (bio-adsorbent) palm fruit fiber in various packed beds connected in series. The maximum percentage of contaminants reduction is 61.78% at 45°C for packed bed, 33.46% at 105°C, and 42.95% at 45°C. The contaminants were subjected to pass through various packed beds, and the process was batch-wise operation. The degree of contaminants (TPH) removal was monitored, and the results obtained were recorded as follows. According to research, room-dried bio-adsorbent palm fruit fiber is useful for treating contaminated water.

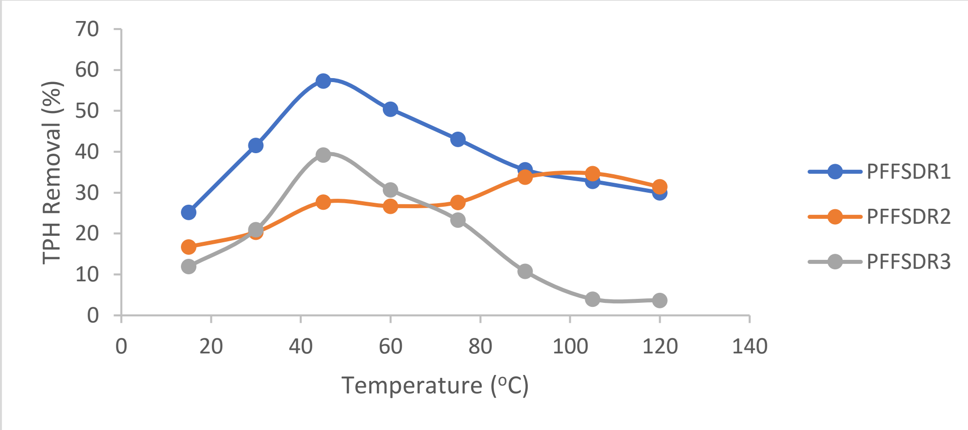

Figure 4 Comparison of Percentage Removal of TPH (Contaminants) in the Three packed Bed versus Temperature Effect for Plantain Stem Sun Dried as Bio-adsorbent

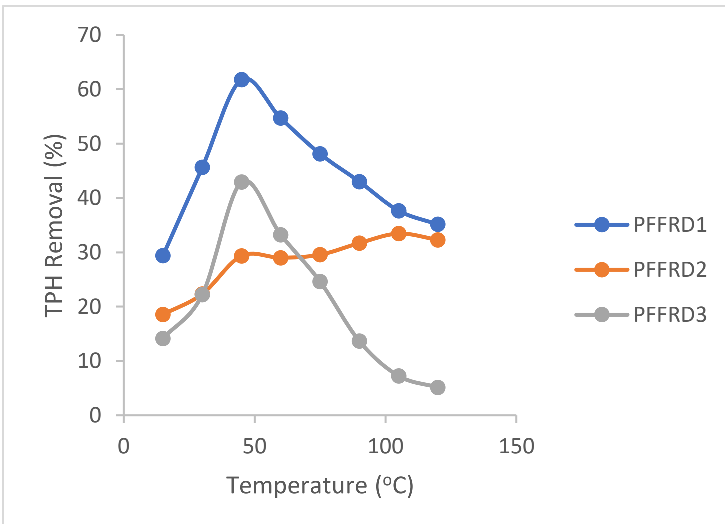

Figure 5 Comparison of Percentage Removal of TPH (Contaminants) in the Three packed Bed versus Temperature Effect for Plantain Stem Sun Dried as Bio-adsorbent

Figure 6 shows comparison of contaminants removal from packed bed connected in series and the temperature effect was examined on the degree of reduction in each packed bed unit. The result reveals 50.23% reduction at 45oC for packed bed unit 1, 18.34% reduction at 60oC for packed bed unit 2 and 9.51% reduction at 105oC for bio-adsorbent of banana stem fibre sun dried based material at maximum contaminant removal. However, the research reveals the significance of banana stem fibre sun dried used in the treatment of contaminated water medium.

Figure 7 compares the three distinct bio-adsorbents (PSSD1, PFFSD1, and BSSD1) employed in packed bed unit 1 to remove pollutants under the influence of temperature. In fact, the comparison shows that the maximum temperature and contaminant reduction for PSSD1 are as follows: 63.21% (45°C), 57.32% (45°C), PFFSD1, and 50.23% (45°C) for BSSD1. The PSSD1 outperformed PFFSD1, then BSSF1, then PSSD1. This indicates that plantain stem fiber that has been sun dried outperformed PFFSD1 and BSSD1 well.

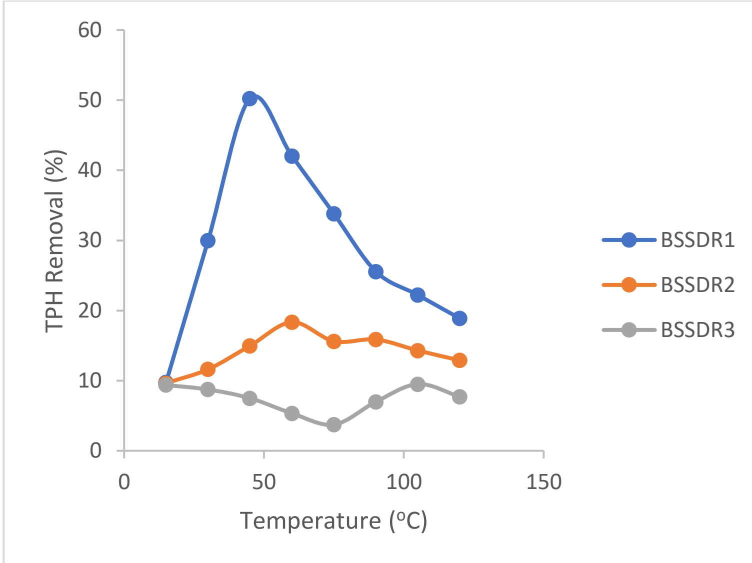

Figure 6 Comparison of Percentage Removal of TPH (Contaminants) in the Three packed Bed versus Temperature Effect for Plantain Stem Sun Dried as Bio-adsorbent

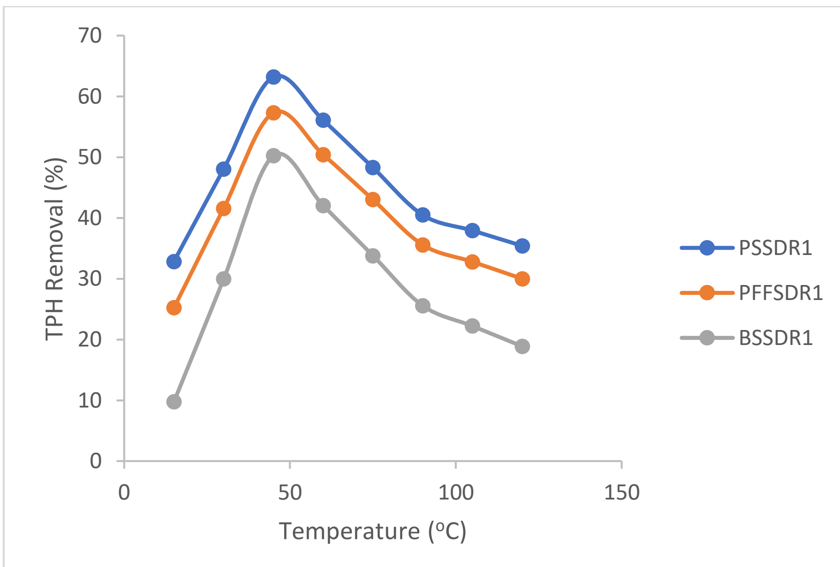

Figure 7 Comparison of the Three Different Bio-adsorbent in Packed Bed Unit 1 for Sun Dried Medium

Figure 8 compares the removal of pollutants (such as TPH or effluent) in packed bed unit 2 employing PSSD 2, PFFSD2, and BSSD2 as bio-adsorbents under the influence of temperature. At 90 oC (PSSD2), 105 oC (PFFSD2), and 60 oC (BSSD2), the highest reduction in contaminants (TPH) elimination is shown to be 37.83%, 34.71%, and 18.34%, respectively. At 90°C, 105°C, and 60°C, the highest reduction by PSSD2> PFFSD2> BSSD2 is shown by the results.

Figure 9 shows the comparison of contaminants treatment at the third stage of the packed bed unit 3 on temperature effect using bio-adsorbent of PSSD3, PFFSD3 and BSSD3. However, the maximum contaminants concentration removal is the third stage of treatment in the packed bed unit reveals 55.34% at 45oC (PSSD3), 39.24% at 45oC (PFFSD2) and 0.51% at 105oC (BSSD3). Maximum performance was experienced at 45oC with 55.34% reduction in contaminant removal followed by 39.24% of the same temperature and lastly 105oC for 0.51% reduction.

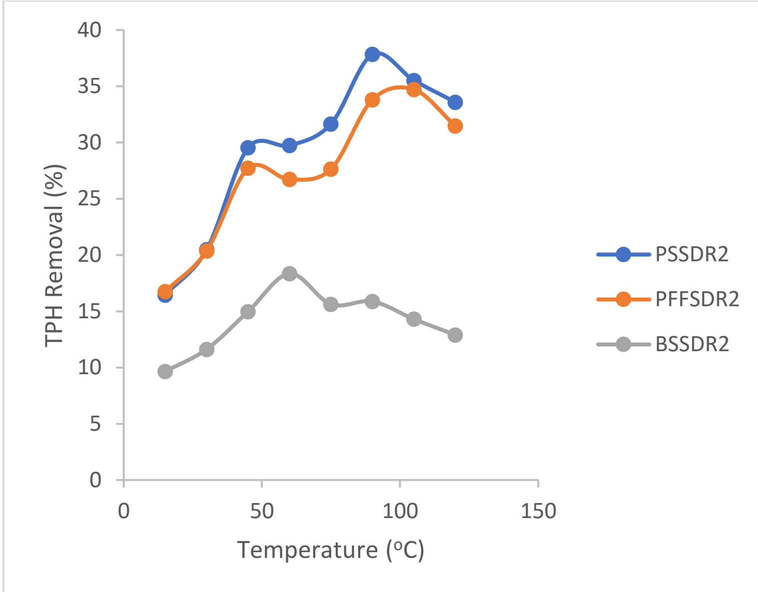

Figure 8 Comparison of the Three Different Bio-adsorbent in Packed Bed Unit 2 for Sun Dried Medium

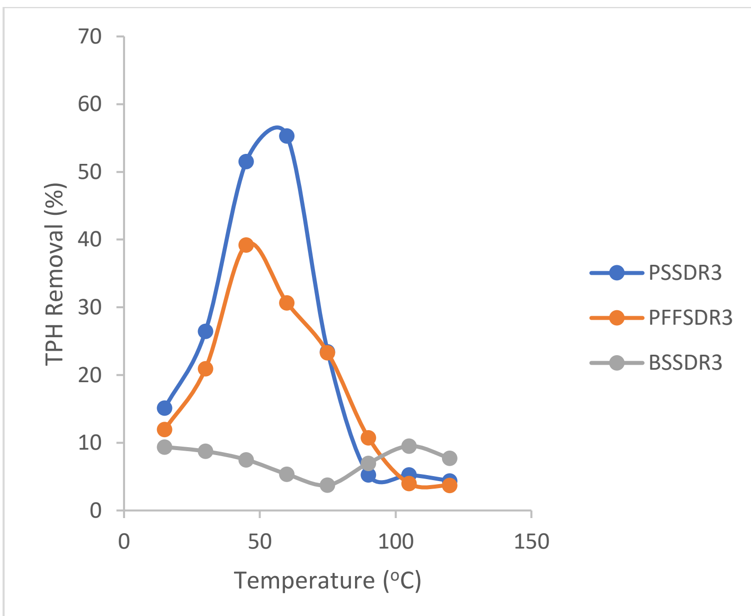

Figure 9 Comparison of the Three Different Bio-adsorbent in Packed Bed Unit 3 for Sun Dried Medium

Figure 10 compares the elimination of TPH (contaminants) after treatment with PSRD1, PFFRD1, and BSRD1 bio-adsorbates on the influence of temperature. The results show that each bio-adsorbent in packed bed unit 1 removed the largest amount of contaminants, with PSSD1 removing 65.83% (45oC), PFFRDI removing 61.78% (45oC), and BSRD1 removing 55.33% (45oC). The elimination of contaminants is reduced in the following order: 65.83% (PSSD1) > 61.78% (PFFRD1) > 55.33% (BSRD1). However, the outcome shows that plantain stem fiber that has been room-dried is more efficient than palm fruit fiber, followed by banana stem fiber, all of which have been room-dried and heated to 45°C.

Figure 11 shows the comparison of contaminants removal using different bio-adsorbent subjected in packed bed unit 2 containing PSRD2, PFFRD2 and BSDD2 on temperature effect. However, the maximum reduction in TPH (contaminants) is demonstrated as 34.77% (90oC) for PSRD2, 33.46% (105oC) for PFFRD2 and 18.80% (75oC) for BSRD2 and the order of magnitude in terms of contaminants removal is 34.77% at 90oC PSRD2 >33.46 at 105oC of PFFRD2 >18.80% at 75oC of BSRD2.

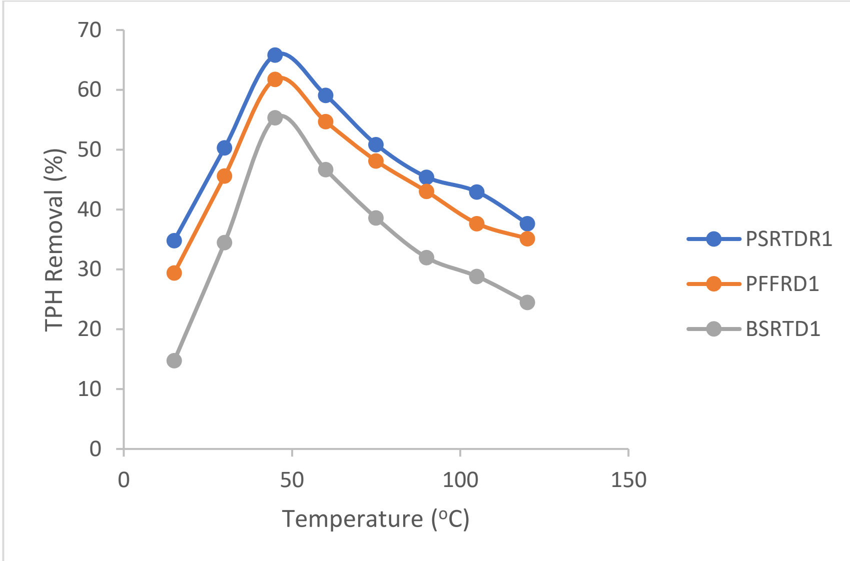

Figure 10 Comparison of the Three Different Bio-adsorbent in Packed Bed Unit 1 for Room Dried Medium

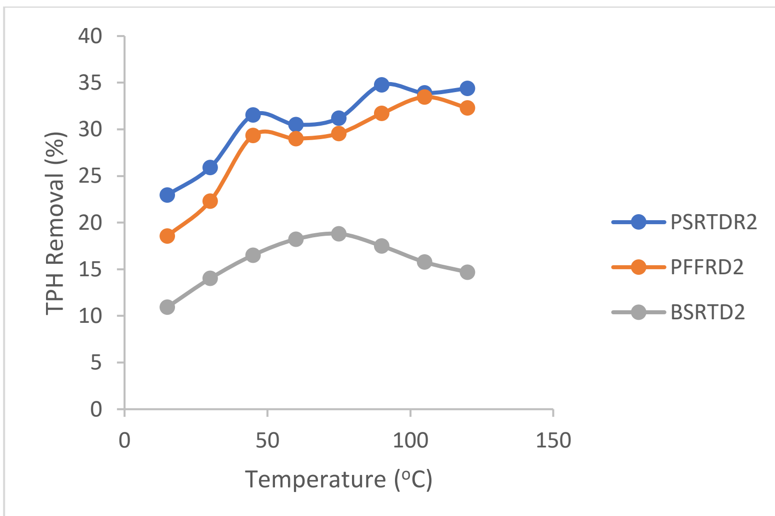

Figure 11 Comparison of the Three Different Bio-adsorbent in Packed Bed Unit 2 for Room Dried Medium

Figure 12 demonstrates the comparison of contaminants reduction using PSRD3, PFFRD3 and BSRD3 as various bio-adsorbent for the treatment of contaminated water medium. The result illustrates the maximum reduction in contaminants removal as follows 52.69% (at 45oC) for PSRD3, 42.95% (at 45oC) for PFFRD3 and 11.12% (at 15oC) for BSRD3. However, it is seen with the view of bio-adsorbent performance that plantain stem fibre is more effective followed by palm fruit fibre of room dried medium for the treatment of contaminated water medium. The result reveals that plantain stem fibre is more effective compared to palm fruit fibre and banana of room dried sample.

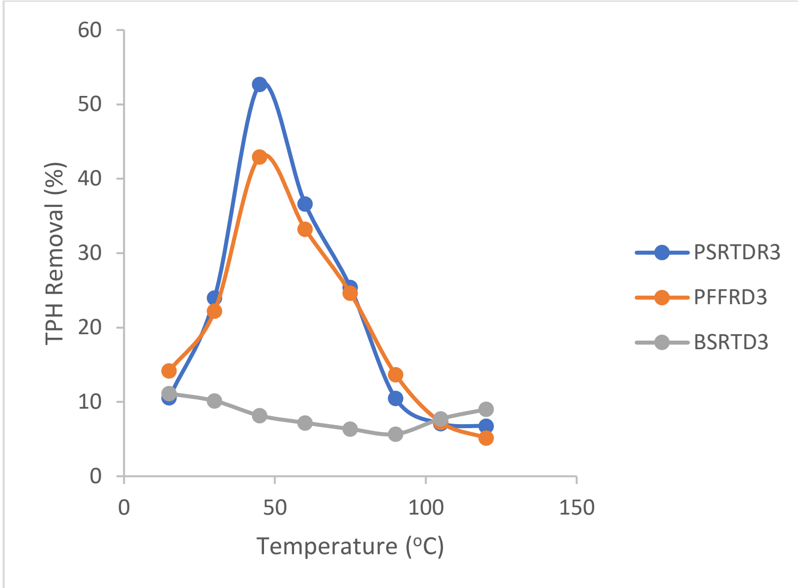

Figure 12 Comparison of the Three Different Bio-adsorbent in Packed Bed Unit 3 for Room Dried Medium

4. CONCLUSION

Based on the adsorbents used (banana, palm, and plantain fiber), the effect of temperature on the degree of total petroleum hydrocarbon reduction in each unit was investigated. The temperature effect shows that at temperatures above 45°C, the majority of contaminants diffuse through the adsorbent without being trapped. All three of the connected in series units exhibited this behavior. The application of bio-adsorbent in packed bed units connected in series for the treatment of contaminated water bodies increased variation in the physicochemical properties of some of the components taken into account, including TDS, Conductivity, Temperature, pH, Chloride, Sulphate, DO, Iron, and Total Hardness. The use of each bio-adsorbent demonstrated its effectiveness in performance in bringing the physicochemical characteristics of the chosen parameters down to the WHO-recommended tolerable limit. The physicochemical characteristics vary actively in response to temperature.

Informed consent

Not applicable.

Ethical approval

Not applicable.

Conflicts of interests

The authors declare that there are no conflicts of interests.

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The study has not received any external funding.

Data and materials availability

All data associated with this study are present in the paper.

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