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Assessing the Influence of Temperature on Physicochemical Characteristics in Fresh Water Contaminated by Crude Oil

[1]Achinike Okogbule-Wonodi; [2]Uku Eruni Philip and [3]Davidson Dimabo Davis

[1&3]Lecturer, Department of Agric and Environmental Engineering, Rivers State University Port Harcourt, Rivers State, Nigeria.

[2]Lecturer, Department of Chemical Engineering, Federal University Otuoke, Bayelsa State, Nigeria.

ABSTRACT

The study investigates the performance of bio-adsorbents—specifically plantain stem fiber, banana stem fiber, and palm fruit fiber—in a packed bed unit for mitigating total petroleum hydrocarbons (TPH) from freshwater environments. The bio-adsorbents were prepared by drying the agricultural materials in sunlight and indoors, then grinding them into powder with particle sizes of 50μm, 150μm, and 200μm, mixed in equal proportions (1:1:1 ratio by mass). Each packed bed unit, connected in series, contained 1500g of this mixed adsorbent. The experimental setup maintained a constant flow rate of 0.2m^3/sec and a packed bed height of 27cm. The primary focus was on evaluating the influence of temperature on physicochemical properties, microbial activity, TPH removal efficiency, residence time, and remediation rates within the packed bed units. Microbial analysis identified predominant microbial strains (PSRTR, PFFRTR, BSRTR, etc.) associated with each bio-adsorbent type under varying temperature conditions. Results indicated higher microbial counts in units using room-dried plantain fiber compared to other configurations (PSRTR1 > PFFRTR1 > BSRTR1, etc.). Notably, room-dried plantain fiber exhibited superior performance across experimental runs (U1, U2, U3). Temperature significantly influenced the bio-adsorption process, impacting fluid penetration, diffusion rates (residence time), and consequently, TPH removal efficiency. Optimal contaminant removal was observed at 45°C, highlighting temperature's pivotal role in enhancing bio-adsorbent effectiveness. This research underscores the critical impact of temperature variations on bio-adsorbent performance in packed bed units during bioremediation processes. Specifically, it highlights the efficacy of plantain fiber in TPH removal when subjected to optimal temperature conditions. These findings contribute valuable insights into optimizing environmental remediation strategies, emphasizing the practical application of agricultural waste-derived bio-adsorbents in mitigating hydrocarbon pollutants from aquatic systems.

Keywords: Bio-adsorbents, Total Petroleum Hydrocarbons (TPH), Packed bed unit, Temperature influence, Microbial activity

INTRODUCTION

Microorganisms are ubiquitous in nature and play a pivotal role in environmental processes, particularly in bioremediation—a mechanism where contaminants serve as a nutrient source for microbial activity. This bioreaction yields environmentally beneficial byproducts such as carbon dioxide (CO2), water (H2O), methane (CH4), heat, biomass, and enhanced microbial growth rates [1-2]

Industries in Rivers State discharge effluents into lakes, rivers, streams, oceans, and seas, significantly altering the natural characteristics of these water bodies [3] These effluents introduce diverse contaminants that serve as essential resources for bacteria and other microorganisms, linking them within aquatic and terrestrial food chains [4].
Microorganisms are vital contributors to global ecosystems, facilitating essential processes like the carbon and nitrogen cycles by continually producing oxygen and nitrogen. Extensive research has explored the diversity of microorganisms, encompassing protozoa, algae, bacteria, viruses, fungi, and other multicellular parasites—most of which are imperceptible without magnification. Microbial characteristics vary widely in terms of size, morphology, physiology, genetics, and metabolic capabilities, highlighting their diverse and complex nature [1-5].
Despite their apparent simplicity, microorganisms exhibit extraordinary complexity in their biochemical and ecological functions, underscoring their significance in ecological balance and environmental sustainability. This complexity necessitates a deeper understanding of microbial interactions and adaptations, particularly in the context of environmental pollution and remediation strategies.

Statement of the Problem

The exploration of crude oil significantly impacts ecosystems, particularly in waterlogged areas like the Niger Delta, through continuous effluent discharge and spills. To mitigate water pollution, bioremediation has been widely employed, with temperature playing a crucial role in its effectiveness. Temperature variations influence both the adsorption capacity of the materials used and the activity of microorganisms in packed bed treatment units or columns. Microbial activity is particularly notable within mesophilic (< 20 to < 45°C), thermophilic (< 20 to < 75°C), and super thermophilic (< 20 to < 105°C) temperature ranges, affecting the efficiency of bioremediation processes [5-7].

Industrial activities, especially crude oil processing, introduce pollutants that severely impact water quality. The toxic nature of crude oil exacerbates environmental degradation when effluents are discharged or spills occur. Consequently, effective treatment methods are imperative to mitigate these pollutants, encompassing physical, chemical, and biological approaches. This study specifically addresses biological methods, utilizing bio-adsorbents such as plantain stem fiber, palm fruit fiber, and banana stem fiber to mitigate petroleum hydrocarbon contamination in freshwater environments [8-10].

The choice of adsorbent significantly influences effluent treatment outcomes. Some adsorbents have shown inadequate performance in reducing the toxic impact of effluent discharge, thereby affecting essential elements and compounds crucial to ecosystem health. To meet environmental standards and ensure reliable effluent discharge, there is a growing need for locally sourced adsorbents with high contaminant mitigation capabilities [11].

To optimize treatment efficacy and compliance with regulatory standards, it is essential to investigate biokinetic and adsorption kinetic parameters under varying temperature conditions. This research aims to elucidate these parameters, providing insights into how temperature influences the efficiency of bio-adsorbents in treating crude oil-contaminated water media. By enhancing our understanding of these dynamics, this study seeks to advance sustainable practices in environmental remediation and contribute to the preservation of aquatic ecosystems [12-18].

METHODOLOGY

Equipment

The following equipment were used for purpose of this thesis, which include:

Equipment/Apparatus

Conductivity meter, glass beakers, volumetric flask (1000 ml), polythene containers, atomic absorption spectrophotometer (AAS), water distillation unit, beakers, graduated pipettes, polypropylene sample containers with polyethylene caps, refrigerator, heating mantle or hot plate, fume cupboard, glass funnel, medium-speed filter paper, valves, PVC pipes for connectors, control wire (line 1 to heater), temperature probe, packed bed cover, recirculation line, control wire (line 2 to pump), unit tank, pump, pressure gauge (electronic or digital in PSI), flexible connectors, heater with temperature controller, packed bed unit, bolts and nuts, circulation pump, control panel (temperature control box), and filter materials.

The research aimed to assess the physicochemical properties and microbial characteristics of crude oil-contaminated water samples collected from the Chemical/Petrochemical laboratory of Rivers State University, Port Harcourt, and the Orashi River at Ahoada Town, Ahoada East Local Government Area. The study focused on understanding these parameters to evaluate the feasibility of using bio-adsorbents for mitigating petroleum hydrocarbon pollution in freshwater environments.

Microbial Isolation and Identification:
Microorganisms present in both the crude oil and water samples were isolated and identified. The enumeration and isolation of aerobic heterotrophic bacteria were conducted using suitable culture media to assess their diversity and potential for bioremediation.

Physicochemical Parameters:
The study included detailed analyses of various physicochemical parameters essential for assessing water quality.

1. pH Determination:
pH levels of both freshwater and contaminated water samples were measured using a calibrated pH meter and electrodes. Calibration against buffer solutions (pH 7.0 and 4.0 or pH 7.0 and 10.0) ensured accurate readings. pH and temperature values were recorded after stabilizing the electrodes in the sample.

2. Alkalinity Determination:
Alkalinity in freshwater was determined by titrating with 0.01M HCl after adding phenolphthalein and methyl orange indicators. For contaminated water, the process involved titration with the same acid solution to achieve endpoints indicated by changes in coloration due to indicators like methyl orange or bromocresol green-methyl red.

3. Conductivity Measurement:
Conductivity, a crucial indicator of water quality, was measured using a calibrated conductivity meter. Standard solutions of potassium chloride (KCl) were employed for calibration to ensure accuracy across different conductivity levels. The meter was adjusted as per manufacturer specifications to account for variations in sample conductivity, particularly in wastewater samples with higher conductivity levels.

4. Total Hardness Assessment:
The hardness of water samples, indicative of calcium carbonate (CaCO3) content, was determined by titration with standard EDTA (ethylene diamine tetraacetic acid) solution. The endpoint, signaled by a color change from wine red to sky blue, allowed calculation of hardness levels in terms of milligrams of CaCO3 per liter (mg/L).

Summary
This comprehensive study provides essential insights into the physicochemical properties and microbial composition of crude oil-contaminated water samples from the Niger Delta region. By employing rigorous analytical methods and standardized protocols, the research aims to contribute to effective strategies for environmental remediation, particularly through the application of locally sourced bio-adsorbents. These findings underscore the importance of understanding water quality parameters and microbial dynamics in mitigating the environmental impact of crude oil pollution, thereby supporting sustainable management practices in aquatic ecosystems. Future studies could further explore optimization strategies for bioremediation processes, ensuring enhanced efficiency and compliance with regulatory standards for effluent discharge and environmental conservation efforts in oil-producing regions.

RESULTS AND DISCUSSION

The concentration of some of the physicochemical selected were monitored based on the performance of the bio-adsorbent used in the different packed bed units as demonstrated in graphs below.

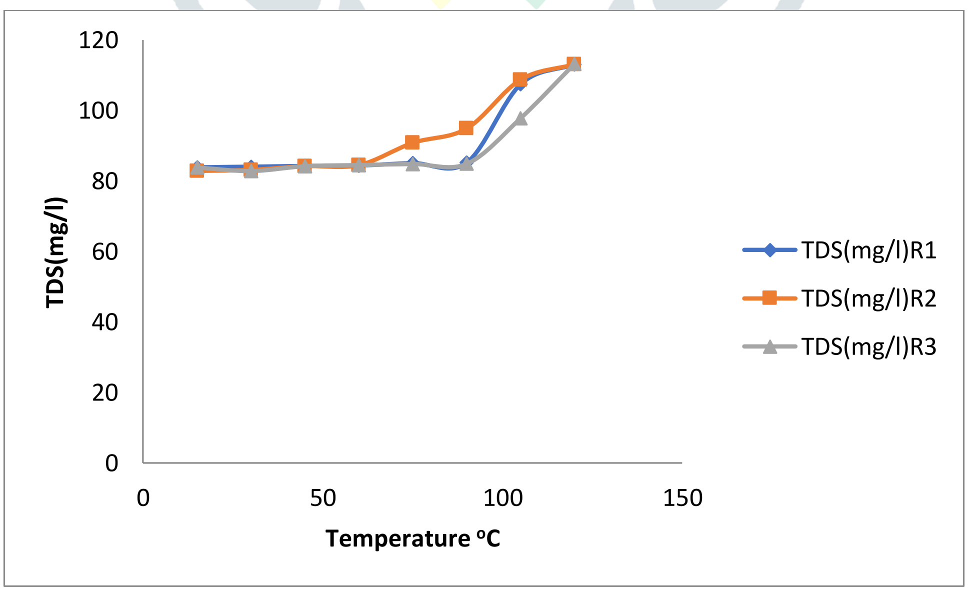

Figure 1: Comparison of Total Dissolved Solid (TDS) Concentration versus Temperature in Various Packed Bed Units (Units 1, 2, and 3 Connected in Series) Using Plantain Fibre Adsorbent

Figure 2 illustrates the correlation between total dissolved solid (TDS) concentration and temperature across three packed bed units (Units 1, 2, and 3 connected in series) using plantain stem fibre as an adsorbent. The TDS concentration increased as temperature rose. This trend indicates that temperature influences the degree of contact and adsorption, with TDS1 showing the highest, followed by TDS2 and TDS3. Variations in TDS can be attributed to temperature fluctuations and the sequence of reactors connected in series.

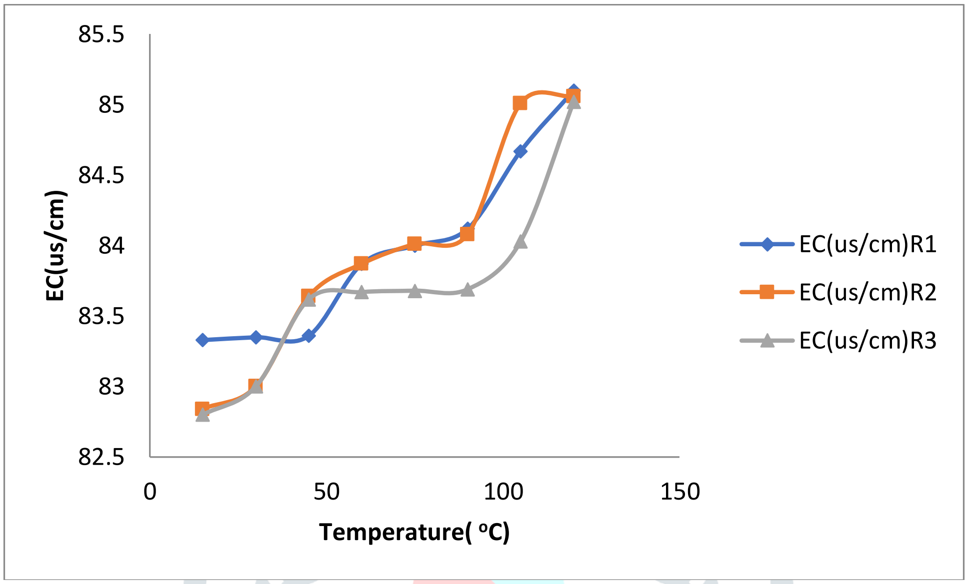

Figure 2: Plot of Electrical Conductivity (EC) Concentration versus Temperature Effect on Different Packed Bed Units 1, 2 and 3 Connected in Series for Plantain Fibre Adsorbent in Packed Bed Units.

Figure 2 illustrates the comparison of electrical conductivity (EC) concentration versus temperature during batch-wise treatment of contaminated water in interconnected packed bed units using plantain stem fibre as a bio-adsorbent. An increase in EC concentration was observed with rising temperature, indicating that higher temperatures enhance contact and adsorption effectiveness, ranked as EC1 > EC2 > EC3. Variations in EC levels can be attributed to temperature variations and the specific configuration of the packed bed units.

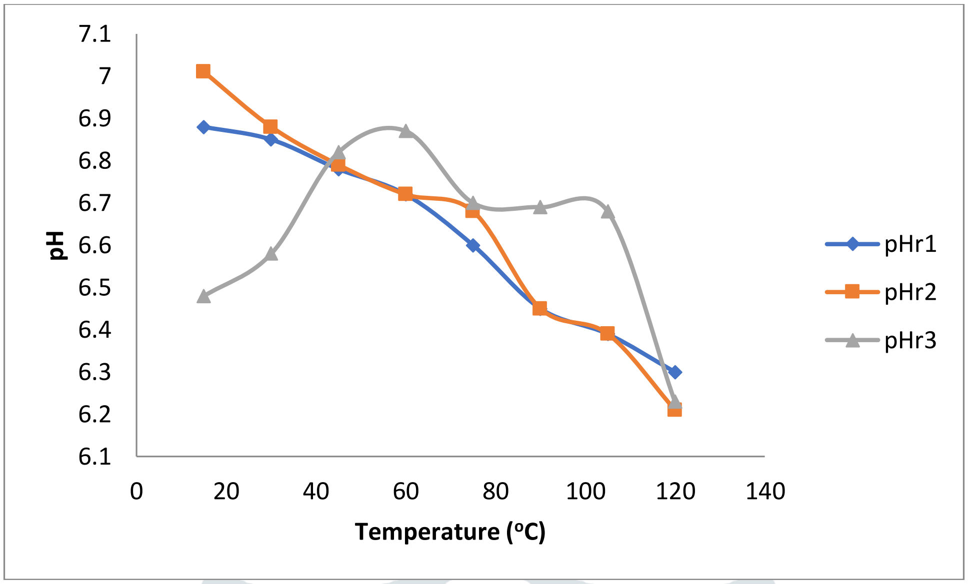

Figure 3: Plot depicting the pH concentration versus temperature effect across interconnected units in series for plantain fibre adsorbent within packed bed systems."

In packed bed unit 3, the initial pH decreases from acidic to a minimum within the temperature range of 15°C to 60°C, followed by an increase in acidity. Figure 3 compares pH values across different packed bed units (1, 2, and 3 connected in series) using plantain stem fibre as a bio-adsorbent, showing a decrease in pH with increasing temperature. This trend indicates that higher temperatures enhance the degree of contact and adsorption performance in the interconnected series of packed bed units

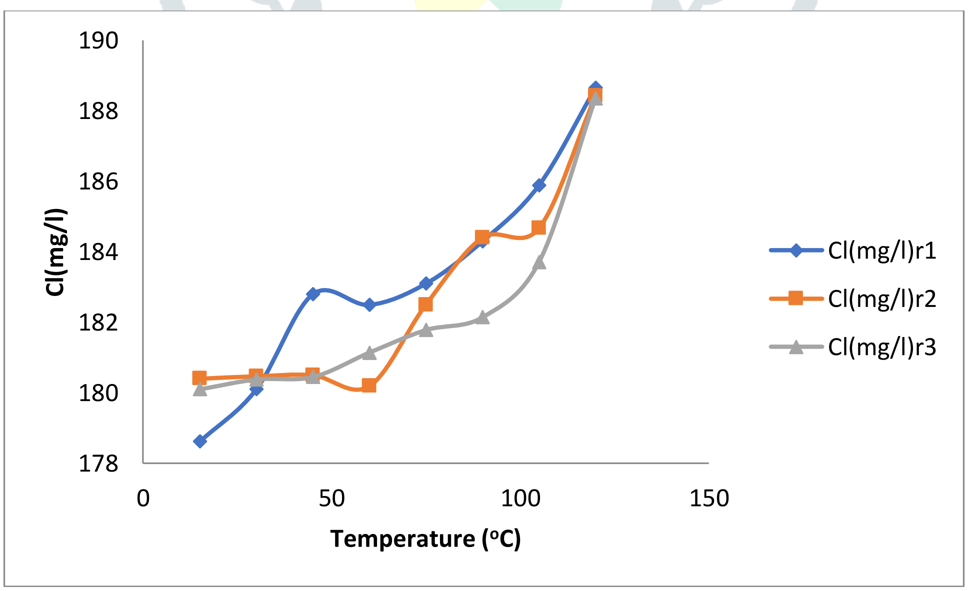

Figure 4: Graph depicting the relationship between chloride concentration and temperature across interconnected packed bed units (Units 1, 2, and 3 in series) using plantain stem fibre as an adsorbent

Figure 4 illustrates the impact of temperature on chloride concentration across various sequentially connected treatment units using plantain fibre as an adsorbent in packed bed configurations. The observed increase in chloride concentration correlates with temperature variations across all interconnected units in series, demonstrating consistent behavior with successive stages

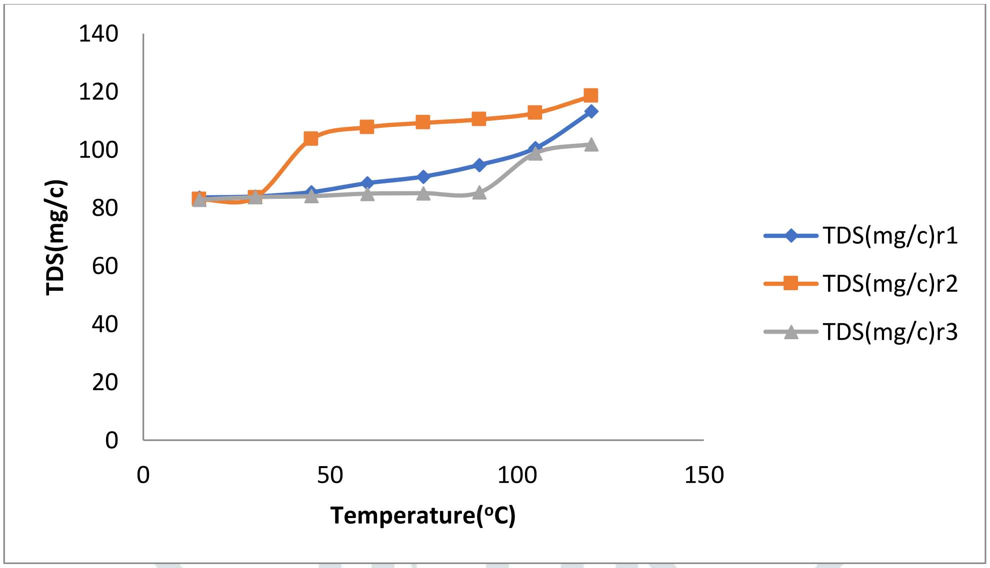

Figure 5: Graph depicting the relationship between total dissolved solid (TDS) concentration and temperature across three interconnected packed bed units (Units 1, 2, and 3 in series) using plantain stem fibre as an adsorbent..

Figure 5 illustrates the comparison of total dissolved solid (TDS) concentration as it varies with temperature. The increase in TDS concentration correlates with higher temperatures across different packed bed units (Units 1, 2, and 3 connected in series) using plantain stem fibre as an adsorbent. This batch-wise process involves the treatment of contaminants (effluent).

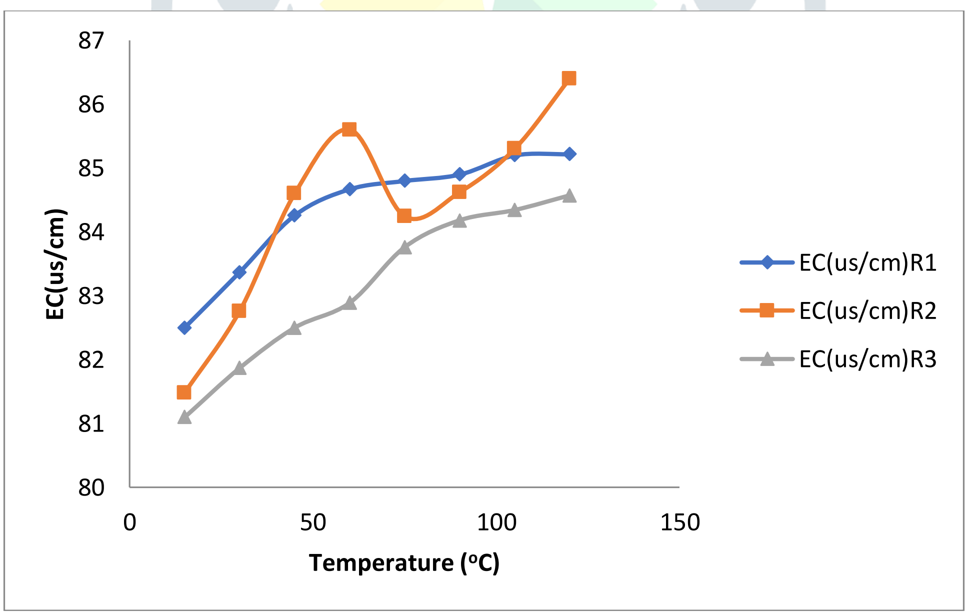

Figure 6: Plot of Electrical conductivity (EC) Concentration versus Temperature Effect on Different Packed Bed Units 1, 2 and 3 Connected in Series for Plantain Fibre Adsorbent in Packed Bed Units.

Figure 6 depicts the comparison of electrical conductivity (EC) concentration in response to temperature variations. The results show an overall increase in electrical conductivity with rising temperature, with a minor deviation observed in packed bed unit 2 between 60°C and 75°C, while packed bed units 1 and 3 show consistent increases. The changes in electrical conductivity are influenced by temperature fluctuations.

CONCLUSION

In conclusion, the experimental results highlight the significant influence of temperature on the behavior of packed bed units containing plantain stem fibre as an adsorbent. The study demonstrated that increasing temperature generally led to higher concentrations of total dissolved solids (TDS) and electrical conductivity (EC) across the interconnected units (Units 1, 2, and 3 in series). These findings underscore the importance of temperature control in optimizing the adsorption process for effective treatment of contaminants in batch-wise operations. Further investigation into the specific mechanisms underlying temperature effects could enhance the efficiency and reliability of such treatment systems.

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