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Removal of Bacteriological Contaminants from Household Wastewater Using Activated Carbon Derived from Sawdust

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Abstract

The increasing concern over bacteriological contamination in household wastewater demands innovative and cost-effective treatment solutions. This study investigated the efficacy of sawdust activated carbon (SAC) as a means to eliminate bacterial contaminants from household wastewater. The sawdust was carbonized in a furnace under anaerobic conditions at 500°C for one hour, it was then activated using phosphoric acid (H_3PO_4). The surface morphology and pore structure of the resulting SAC were analyzed using Scanning Electron Microscopy (SEM) and X-ray diffraction (XRD). The SEM image displayed a highly porous structure with many cavities and channels essential for adsorbing bacteriological contaminants. The XRD pattern revealed a prominent peak indicating a substantial presence of graphite, which enhances adsorption properties and is vital for removing contaminants from water. Batch adsorption experiments evaluated the removal efficiency of Escherichia coli (E.coli) and total coliform bacteria. The SAC doses tested were 5g, 10g, and 15g, combined with contact times of 30 minutes, 60 minutes, and 120 minutes. Results showed a significant reduction in bacterial counts, indicating that SAC is a viable material for decentralized wastewater treatment systems. Higher dosages and longer contact times significantly improved the reduction of E.coli and total coliforms, with the best results observed at a 15g dosage and a 120-minute contact time, achieving 96% reduction for E.coli and 93% reduction for total coliforms.

1.0. Introduction

Water contamination by pathogenic bacteria is a major public health issue, particularly in regions with inadequate wastewater treatment infrastructure [1, 2, 3]. Conventional treatment methods, while effective, can be costly and complex [4, 5, 6, 7, 8]. Household wastewater, comprising greywater (from sinks, baths, and washing machines) and blackwater (from toilets), often contains various contaminants, including pathogens such as total coliform and Escherichia coli (*E.coli*) [9, 10]. These contaminants pose significant public health risks, necessitating effective treatment methods [11].

Household wastewater significantly contributes to environmental pollution, containing organic and inorganic compounds, pathogens, nutrients, and suspended solids [12, 13]. Bacteriological contaminants, especially total coliform and *E.coli*, indicate fecal contamination and present serious health hazards [14, 15]. Total coliform encompasses a wide range of bacteria found in the environment, such as in soil, vegetation, and water [16]. Their detection in water suggests potential pathogen contamination [17]. *E.coli*, a specific subset of coliform bacteria, resides in the intestines of warm-blooded animals, and certain strains can lead to severe gastrointestinal illnesses [18].

Traditional wastewater treatment processes include primary, secondary, and tertiary treatments [19, 20]. These methods are effective but often expensive and complex, involving various physical, chemical, and biological processes to remove contaminants [6, 7, 20]. Primary treatment involves the physical separation of large particles and solids through screening and sedimentation [21]. Secondary treatment involves biological processes such as activated sludge or biofilm systems, to degrade organic matter and reduce biochemical oxygen demand (BOD) [22]. Tertiary Treatment involves advanced methods like filtration, chlorination, UV irradiation, and activated carbon adsorption to remove residual contaminants and pathogens [23, 24].

Activated carbon is renowned for its high surface area and adsorption capacity, making it effective for removing a wide range of contaminants, including organic compounds, heavy metals, and pathogens [25]. Adsorption involves the adhesion of contaminants to the surface of activated carbon particles. The efficiency depends on the surface area, pore size distribution, and surface chemistry of the activated carbon. Activated carbon is widely recognized for its adsorption properties, but commercially available activated carbon can be expensive, prompting the search for cost-effective alternatives. Activated carbon is widely used for water purification due to its high adsorption capacity, but there is growing interest in low-cost alternatives like sawdust activated carbon (SAC). Sawdust, a plentiful by-product from the timber industry, provides a cost-effective material for creating activated carbon [26, 27, 28]. This by-product, generated from woodworking processes like sawing, milling, planning, and drilling, has attracted considerable attention recently because of its versatility and wide range of potential applications [21, 29, 30]. Often considered waste, sawdust possesses significant potential across numerous sectors due to its distinct physical and chemical properties.

The production process of SAC includes carbonization and activation [31]. Carbonization is the heating of sawdust in the absence of air to convert it into char while activation involves treating char with activating agents like phosphoric acid or steam to develop a porous structure [32, 33, 34]. The activation process involves chemical or physical activation to enhance porosity and surface area. SAC utilizes waste material, contributing to waste management and resource efficiency.

Several studies have explored the use of SAC for removing bacteriological contaminants from wastewater, demonstrating its potential as an effective and affordable adsorbent [8, 35, 36, 37, 38]. The use of SAC in removing bacteriological contamination from household wastewater offers a promising, cost-effective, and sustainable solution [39]. While there are challenges to be addressed, the existing body of research indicates significant potential for SAC in improving water quality and protecting public health, particularly in resource-limited settings [40]. This study explores the potential of SAC as an effective alternative for bacteriological decontamination of household wastewater.

2.0 Materials and Methods

2.1 Preparation of Sawdust Activated Carbon

Sawdust was sourced from a local sawmill in Akure, Southwestern Nigeria and thoroughly washed with distilled water to eliminate impurities. The cleansed sawdust was subjected to drying at 105°C for 24 hours. The dried sawdust was subjected to carbonization in a muffle furnace under air-free conditions at 500°C for a duration of 1 hour. The resulting char was activated through a chemical process utilizing phosphoric acid (H_3PO_4) and subsequently heated to 450°C for 2 hours [41].

2.2 Characterization of SAC

The surface characteristics and pore architecture of the SAC were examined through Scanning Electron Microscopy (SEM) and X-ray diffraction (XRD), with SEM images providing visual insights into the structure. SEM analysis involved bombarding the surface of the sample with a focused beam of electrons, which interacted with the atoms to produce signals such as secondary electrons, backscattered electrons, and characteristic X-rays [42]. These signals were then detected and translated into a detailed image of the surface morphology and microstructure of the sample [43]. XRD analysis entailed directing X-rays at the sample, which caused diffraction due to the interaction between the X-rays and the crystal lattice of the material. The resulting diffraction pattern provided information about the crystallographic structure of the sample, including the spacing of the lattice planes and the identity of the crystalline phases present [44].

2.3 Wastewater Characterization

Household wastewater samples were gathered and analyzed for initial bacteriological content, including total coliforms and E.coli. Batch adsorption experiments were performed by adding different amounts of SAC (5g, 10g, and 15g) to 500 mL of wastewater in conical flasks. The mixtures were agitated with mechanical stirring at 150 rpm at room temperature for 30, 60, and 120 minutes to ensure proper contact. After agitation, the samples were filtered, and the filtrates were tested for bacterial presence using the membrane filtration method. Samples were periodically extracted at 30, 60, and 90-minute intervals during the adsorption process to measure the effectiveness of SAC in removing bacterial contamination. The analysis followed [45, 46] protocols, which involved passing a specific volume of water through a membrane filter to capture bacteria. The filter was placed on selective agar to inhibit non-coliform bacteria growth, allowing coliforms to grow. After incubation, colonies were counted, and typical coliform and E.coli colonies were confirmed with biochemical tests. All experiments were carried out in triplicate and the average values were used in the evaluation.

2.4. Percentage reduction of *E.coli* and total coliform in wastewater

The percentage reduction of *E.coli* and total coliform in wastewater in the SAC-treated wastewater was calculated using equation (1) [47].

$$Percentage\ Reduction = \frac{C_1 - C_2}{C_1} \qquad (1)$$

C_1 denotes the initial concentration of *E.coli* or total coliform prior to treatment, measured in colony-forming units per milliliter (CFU/ml), while C_2 signifies the concentration of *E.coli* or total coliform following treatment, also measured in CFU/ml.

3. Results and Discussion

3.1 SEM results

The SEM image of sawdust activated carbon at 500x magnification, depicted in Figure 1, reveals a highly porous and uneven surface morphology. This structure, with numerous cavities and channels, greatly increases the surface area available for adsorption, enhancing its efficiency in trapping bacteria and other contaminants [48, 49]. Aggregated particle clusters visible in the image contribute to the mechanical stability of the activated carbon, making it effective as a filtration medium [50, 51]. The porous nature ensures a large surface area crucial for adsorbing bacteriological contaminants, while the rough surface prolongs contact time between wastewater and activated carbon, facilitating more effective adsorption [33, 52, 53]. This process is essential for reducing bacterial load in wastewater, meeting water safety standards, and protecting public health [54]. In summary, the highly porous and uneven surface of SAC increases surface area and contact time for effective bacterial adsorption.

3.2 XRD results

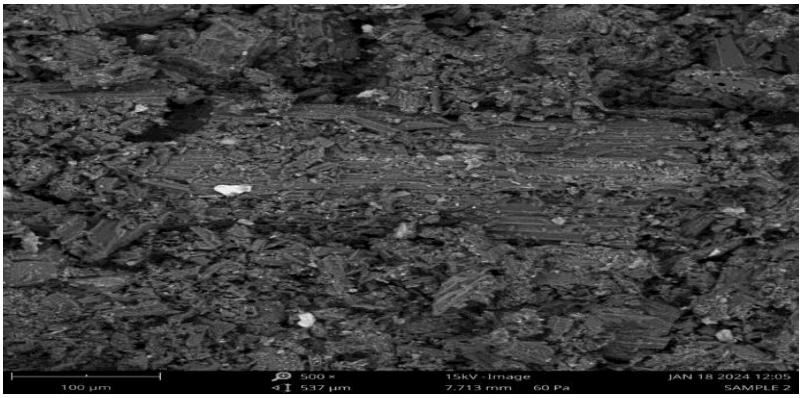


Figure 1: SEM image of SAC

Figure 2 presents the XRD results, revealing that sawdust activated carbon contains a significant amount of carbonate-apatite (87.1%) and graphite (6.39%), indicating a high carbon content [55]. This high carbon content is essential for adsorption processes, providing a large surface area for trapping and removing contaminants, including bacteria, from wastewater [56]. The activated carbon's porous structure enhances its ability to adsorb and retain bacteriological contaminants [57, 58, 59]. This porosity effectively traps bacteria, preventing their passage through the [60, 61, 62].

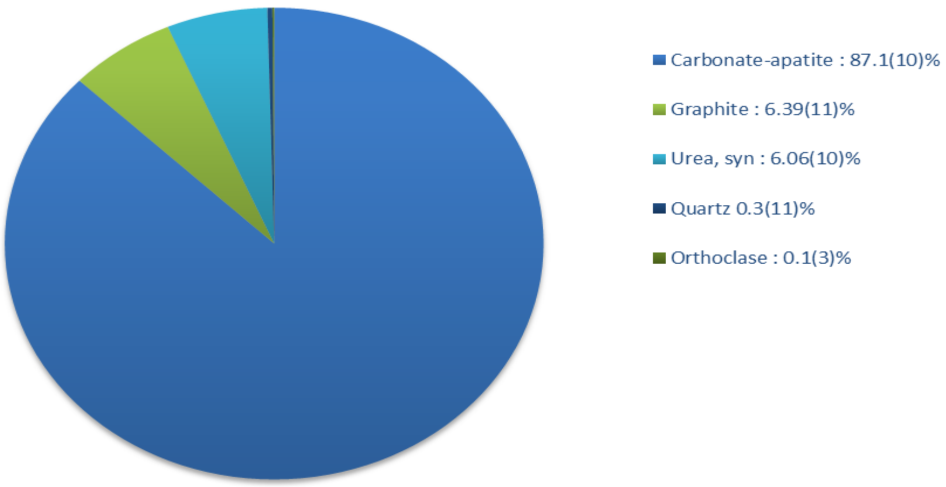


Figure 2: XRD results for SAC

3.3 XRD pattern

The XRD pattern of the sawdust activated carbon sample illustrated in Figure 3 shows the presence of multiple crystalline phases, including graphite, carbonate-apatite, urea, quartz, and orthoclase. The prominent peak around 26° 2θ indicates a significant amount of graphite, which is beneficial for adsorption properties crucial for removing contaminants, including bacteria, from water [63, 64]. The presence of carbonate-apatite suggests enhanced capability for removing heavy metals and other ions, while quartz and orthoclase might be residual minerals from the sawdust or introduced during the activation process [65]. These phases collectively contribute to the material's effectiveness in purifying water [66].

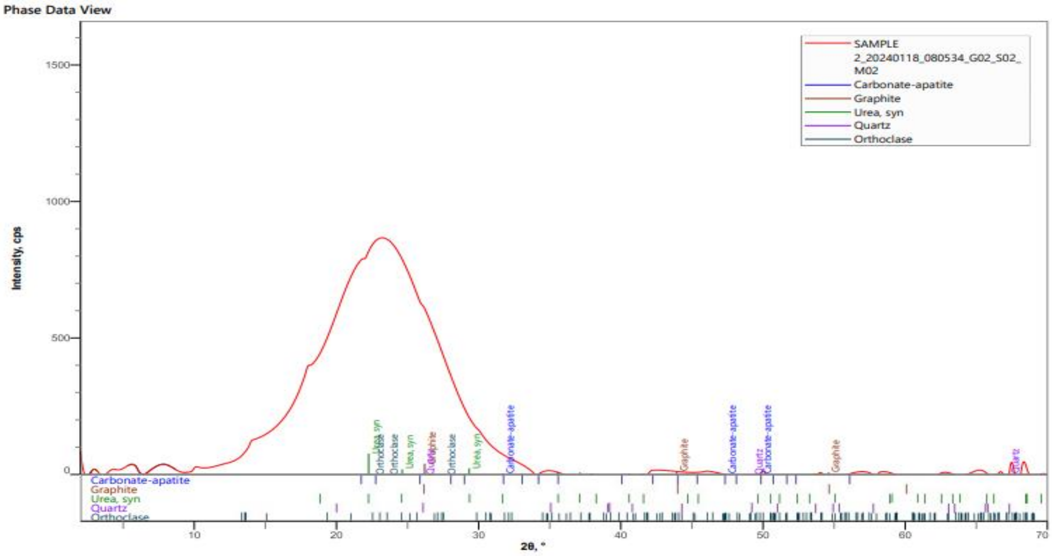


Figure 3: X-Ray Diffraction pattern of SAC

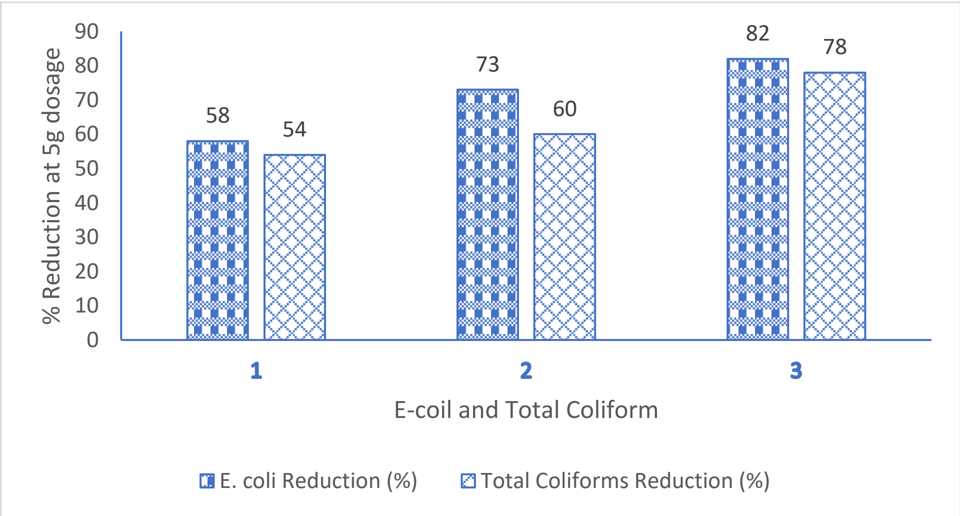
In summary, XRD results reveal a high carbon content which enhances SAC's ability to trap and remove bacteria. The combined porous structure and varied chemical composition make SAC an efficient option for wastewater treatment, effectively reducing bacterial contamination.

3.4 Bacteriological Removal Efficiency

Starting with initial concentrations of 221 CFU/ml for *E.coli* and 1.5 x 10^4 CFU/ml for total coliforms in the wastewater, Figures 4, 5, and 6 portray the percentage reductions of *E.coli* and total coliforms achieved through treatment procedures employing various doses and contact times. The tested doses included 5g, 10g, and 15g, coupled with contact durations of 30 minutes, 60 minutes, and 120 minutes. The bacteriological examination revealed a notable decline in bacterial counts with higher doses of SAC and longer contact durations. At a 5g dosage, *E.coli* reduction was 58% and total coliforms reduction was 54% after 30 minutes. Increasing the contact time to 60 minutes enhanced the *E.coli* reduction to 73% and total coliforms reduction to 60%. Extending the contact time to 120 minutes further improved the reductions to 82% for *E.coli* and 78% for total coliforms. With a 10g dosage, the reductions were more pronounced. After 30 minutes, *E.coli* reduction was 69% and total coliforms reduction was 63%. At 60 minutes, *E.coli* reduction rose to 83% and total coliforms reduction to 77%. At 120 minutes, reductions reached 86% for *E.coli* and 85% for total coliforms. The highest dosage of 15g produced the most substantial reductions. At 30 minutes, *E.coli* reduction was 77% and total coliforms reduction was 71%. Increasing the contact time to 60 minutes resulted in an *E.coli* reduction of 89% and total coliforms reduction of 86%. At 120 minutes, the reductions peaked, with *E.coli* reduction at 96% and total coliforms reduction at 93%.

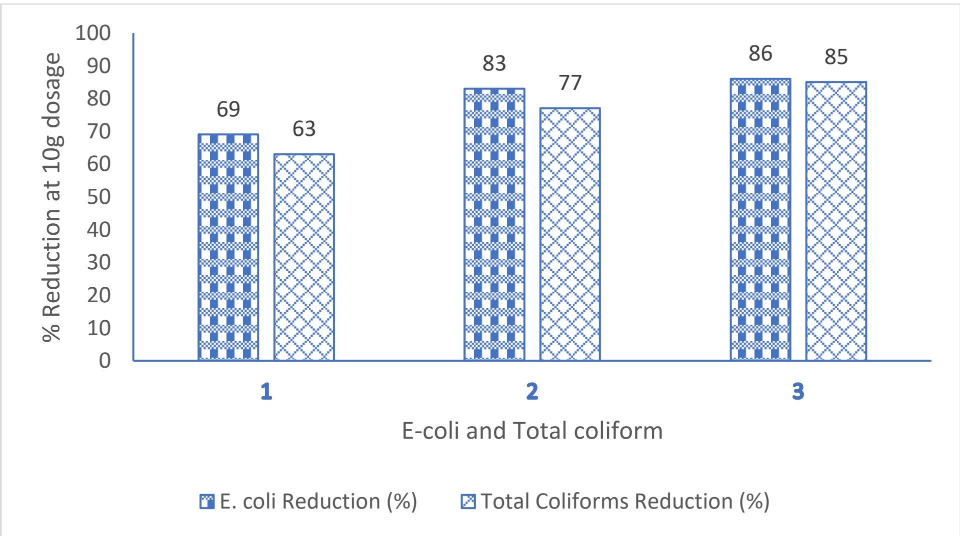
E. coli was consistently removed more effectively than total coliforms at all doses and times, likely due to differences in bacterial cell wall composition. E. coli's simpler cell wall structure may be more susceptible to adsorption compared to the more complex, thicker walls of total coliforms [67]. The porous structure of SAC, as seen in the SEM images, allows for extended surface area, thereby enhancing the chances of bacterial contact and adhesion. As contact time increases, the prolonged interaction between bacteria and the SAC's porous surfaces leads to improved trapping and adsorption. Longer durations also allow for more physical entrapment of bacteria in the pores and potentially more time for adsorption processes to occur, this further improves the removal efficiency. Additionally, the graphite and carbonate-apatite content of SAC observed in XRD

analysis may contribute to its effectiveness by offering surfaces for bacterial adhesion and aiding in the capture of bacteria through adsorption mechanisms. The improvement in removal efficiency with time can also be attributed to the saturation of the activated carbon, where prolonged exposure enhances the likelihood of the bacteria being adsorbed before the media reaches full capacity [68].
In summary, the findings indicate that higher doses and prolonged contact durations notably improve the reduction of *E.coli* and total coliforms. Optimal reduction occurred with a 15g dosage and 120-minute contact time, achieving a 96% decrease for *E.coli* and a 93% decrease for total coliforms. It was observed that the reduction in *E.coli* slightly exceeded that of total coliforms across all doses, although this distinction diminished with longer contact periods. This suggests that as contact times increase, the treatment's efficacy against both types of bacteria becomes more comparable. These results are consistent with the findings of [69, 70]. Furthermore, extending the contact time enhances the overall efficacy of the treatment for both *E.coli* and total coliforms, with the most significant reductions observed at 120 minutes, indicating that prolonged exposure to the treatment leads to improved disinfection outcomes.



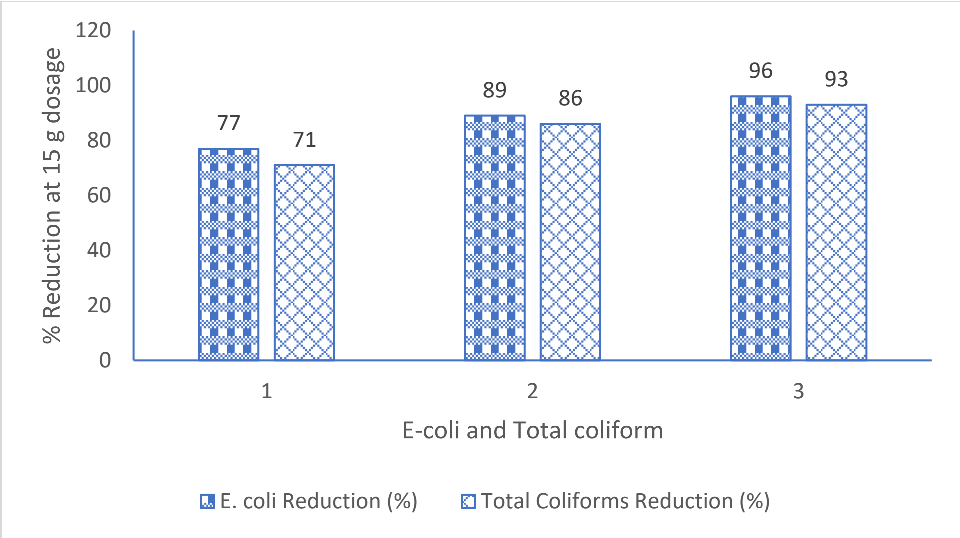
Where 1 is 30 minutes contact time, 2 is 60 minutes contact time and 3 is 120 minutes contact time

Figure 4: E-coli and total coliform reduction at 5g dosage



Where 1 is 30 minutes contact time, 2 is 60 minutes contact time and 3 is 120 minutes contact time

Figure 5: E-coli and total coliform reduction at 15g dosage



Where 1 is 30 minutes contact time, 2 is 60 minutes contact time and 3 is 120 minutes contact time

Figure 6: E-coli and total coliform reduction at 15g dosage

4. Conclusion

The research affirms that sawdust activated carbon (SAC) proves to be an efficient adsorbent for eliminating bacteriological impurities from domestic wastewater. The SEM image displays SAC's notably porous and rugged structure, highlighting its efficacy in purifying wastewater by increasing surface area, extending contact duration, and employing effective trapping mechanisms. XRD analysis of SAC indicates a significant presence of carbonate-apatite and graphite, underscoring its ability to adsorb bacterial contaminants due to its porous nature, varied chemical composition, and bacteriostatic properties. Prolonged contact time notably enhances treatment efficacy against both *E.coli* and total coliforms, with optimal reduction rates observed after 120 minutes, suggesting longer exposure improves disinfection outcomes. From this study. the optimal dosage needed for effective bacterial removal from household wastewater is 15g of SAC at 120 minutes contact time. The substantial removal efficiencies suggest SAC could serve as a viable and eco-friendly alternative to traditional treatment methods, especially in resource-constrained environments. To minimize environmental impact and ensure safe handling of contaminants, it is recommended to explore environmentally friendly disposal options for the used sawdust activated carbon (SAC), such as composting, use as soil amendments, and conversion to energy through pyrolysis. These methods can not only reduce waste volume and generate renewable resources but also enhance soil health and agricultural practices.

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