



**Feasibility of Removing Fats, Oils, and Grease (FOG) from Industrial Wastewater
Using Banana Peel-Derived Biochar**



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ABSTRACT

FOG in industrial wastewater represents a significant problem in terms of treatment and environmental impacts, particularly for communities with food processing industries. This study aimed to evaluate the feasibility of banana-peel-derived biochar as a low-cost and sustainable filter medium for FOG removal from industrial wastewater. A prototype filtration tube, fed by gravity, was prepared with banana-peel biochar and tested with industrial wastewater samples. The experiment had been conducted as a single demonstration wherein qualitative observation and photo documentation were used as the treatment performance analysis. After filtration, the following qualitative improvements were noticed in the treated wastewater: it became clearer, lighter in color, and considerably less odorous, where the filtered sample is almost odorless when compared with the non-filtered sample. These qualitative improvements in clarity, color, and odor indicated the possible removal or reduction of FOG containing surface oil films and suspended particulates. In addition, the filtered water's biochar color turned darker after treatment, indicating the possible adsorption of contaminants. This prototype demonstrated visible improvement in wastewater quality, indicating feasibility for early-stage pre-treatment applications. However, no laboratory analyses of FOG or other pollutants were performed, and results are entirely based on visual and sensory evidence. Overall, the results indicate that banana-peel biochar can be an effective and promising way to visibly improve the quality of wastewater under practical conditions, showing great promise in resource-constrained regions. However, further studies using laboratory analyses, replicate trials, and optimization of filter design should be performed to scientifically confirm and scale up this approach.

Keywords: banana-peel biochar, industrial wastewater, fats oils and grease (FOG), filtration, qualitative observation, sustainable treatment

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1. INTRODUCTION

Background of the Study

Globally, fats, oils, and grease (FOG) from industrial sources are responsible for numerous sewer overflows and infrastructure problems. Industrial facilities, such as food and beverage processing plants, slaughter houses and factory grease-trap operations generate a significant amount of FOG in waste waters submitted to waste water treatment systems. Industrial waste waters usually contain very high concentrations of FOG. For example, slaughter houses use tremendous amounts of water for processing livestock, producing waste waters containing large amounts of animal fats and processing oils (Sam, 2025).

The presence of FOG in industrial wastewater increases both structural and environmental problems beyond those typical of simple municipal systems. Industrial FOG tend to solidify and build up in sewer systems, forming obstructions and blocks wastewater flow. This results in sewer overflows, damages in the pipes, and deterioration in the infrastructure. In some industrial settings, FOG accounts for 25–35% of the total chemical oxygen demand in wastewater entering treatment plants, creating substantial operational challenges. Food processing industries face particularly severe consequences, with treatment plants becoming overloaded and requiring costly operational and treatment procedures (Netsol, 2022).

Manufacturing processes also contribute significantly to industrial FOG discharge through drawing oils, stamping oils, machining oils, buffing compounds, and various industrial lubricants. Regulatory agencies set strict standards for industrial users and prohibit the discharge of petroleum oils and mineral oil products that interfere with treatment systems. Many publicly owned treatment works set pretreatment limits near 100 mg-L^{-1} for FOG discharge from industrial facilities (Hubbard-Hall, 2024).

To address these problems, researchers investigate natural and organic materials as sustainable possible treatment solutions. Banana peels is a good option because of their porous structure and wide availability. Industrial regions, particularly in developing countries such as the Philippines where Tagum City in Davao del Norte serves as an agricultural and industrial hub, generate a large amount of banana waste from both production and food-processing operations (Escosio, 2025).

Banana peels have a porous structure and surface functional groups that favor adsorption, making them suitable for conversion into biochar. Through slow pyrolysis, a process of heating banana peels under limited oxygen, the peels are converted into highly porous, carbon-rich biochar with adsorption properties. Laboratory studies on banana-peel-derived activated carbon report strong removal of oils, organics, and some heavy metals under optimized conditions; reported removal ranges vary by contaminant and method, with some studies citing values up to about 80–97% in specific laboratory tests. Reported surface areas for activated forms may be high (literature values vary), and optimized pyrolysis conditions have been shown to improve oil adsorption performance while balancing yield and energy use (Urgel et al., 2024).

Using banana-peel biochar for industrial FOG removal offers a low cost and sustainable advantage compared with chemical and mechanical methods, which are often expensive and requires high maintenance. A filtration tube containing a dense bed of banana-peel biochar allows wastewater to contact with the biochar as it flows by gravity, providing contact time and this setup is especially suitable for small-scale pre-treatment of FOG. This approach is appropriate in areas where banana waste is abundant, such as the Davao region, which could support local and integrated treatment systems (Banana Link, 2021).

Although banana-peel biochar performs well in laboratory studies, few investigations have tested it with real, complex industrial FOG wastewater, and optimal production parameters for industrial use remain unclear. This research addressed that gap by evaluating a simple, low-cost gravity-fed filtration tube packed with banana-peel biochar as a practical pre-treatment for industrial FOG-containing wastewater. At the prototype stage, performance was assessed qualitatively through visual and physical observations (for example, water clarity, visible oil film, and biochar condition) and interpreted in the context of published literature. The study's objectives were to assess prototype feasibility, observe apparent FOG capture under real conditions, and evaluate practical scalability for local, low-cost applications (Teriku & Meskel, 2022).

Research Questions

The following research questions were formulated to guide this study in evaluating the feasibility of the prototype in using banana peel biochar for treating fats, oils, and grease (FOG) in industrial wastewater:

1. What is the design feasibility of a slow-pyrolysis banana-peel biochar filtration tube for mitigating fats, oils, and grease (FOG) in industrial wastewater?
2. How can prototype observations guide recommended biochar amount and residence time to visibly reduce FOG?

Engineering Goals

The prototype will be a modular, gravity-fed filtration tube that can be opened for filling and inspection. It will be designed and built from low-cost, locally available materials so assembly and maintenance are simple for non-specialists. The column will allow easy packing and removal of banana-peel biochar and will be stable during operation.

The prototype will demonstrate visible reduction of fats, oils, and grease (FOG) in industrial wastewater during a controlled run and documented with photographs as well as written observations. The filtration tube will include pebbles at the top along with biochar and a mesh filter to promote even flow. The design will aim for gravity-driven filtration appropriate for small industrial loads without rapid clogging, having operation and safety as top priorities. The prototype will be safe to use outdoors with appropriate and proper PPE, fire-safety measures for pyrolysis, and containment for

used wastewater. After runs, the spent biochar will be inspected visually and handled for safe disposal according to guidelines.

Finally, the project will minimize material cost and make use of existing materials within the researchers' house and be responsible regarding the disposal of used biochar. Clear assembly, operation, and maintenance instruction will be provided so others can replicate the prototype. The study will document limitations and produce a short plan for laboratory validation and scaled testing as follow-up work.

Significance of the Study

The build-up of fats, oils, and grease (FOG) in industrial wastewater poses a lot of challenges to wastewater treatment facilities worldwide, the FOG found in wastewater could lead to blockages and obstructions in the pipes, sewer overflows, and costly damage to infrastructures. The presence of FOG not only disrupts the operation of treatment plants but it can also harm the environment by reducing oxygen transfer in aquatic ecosystems (Team One Biotech, 2025). Addressing this problem is important to help maintain environmental health, especially in industrial hubs such as Tagum City, Philippines, where agricultural and industrial activities generate FOG wastewater.

This study is significant as it explores the feasibility and potential of using the prototype with banana peel-derived biochar, an abundant agricultural waste to be used as a sustainable, low-cost adsorbent for removing FOG from industrial wastewater. Banana peel biochar shows promising potential in removing FOG due to its porous carbon structure and surface functional groups, which gives it the ability to capture FOG (Al-Sareji et al., 2024). Using this biochar not only provides an innovative idea to wastewater treatment but helps to waste removal by making use of banana peel waste into a valuable resource.

Furthermore, this research addresses gaps by testing a practical gravity-fed filtration prototype with industrial wastewater, helping offer insight into the design feasibility, operational potential, and scalability of biochar filtration systems for local and practical applications. By showing visible improvements in water clarity and reduction of grease films, the study supports environmentally friendly wastewater management solutions that are accessible and can help to communities with limited resources. The findings could guide future optimization, improvement and implementation of biochar-based treatment technologies, in which ultimately promoting sustainable industrial practices and environmental protection (Fang et al., 2025).

Review of Related Literature

Fats, Oils, and Grease

The presence of fats, oil, and grease (FOG) is a growing problem for agricultural and industrial wastewater facilities. When FOG goes into sewer systems from food-processing plants, slaughterhouses, and other facilities. The release in the sewer system causes a build-up of FOG and eventually numerous of problems occur such as the blockage of pipes, foul odors, maintenance issues (Husain et al., 2014). Their release into aquatic environments forms surface films that slow down and stop oxygen transfer which disrupts aquatic life (EPA, 2023). Due to these operational and environmental impacts, FOGs removal from Industrial wastewater is vital to keep facilities in order and avoid hurting the environment (Lagos et al., 2023).

Traditional treatment processes for FOGs such as skimming, grease traps and chemical saponification remove or decompose FOG for disposal, but these processes tend to be expensive to operate, require constant maintenance and appropriate waste management to prevent secondary contamination (Thakur et al., 2024). In addition, chemical treatments may produce by-products that pose extra disposal challenges to wastewater treatment microbial populations, particularly when surfactants are used (He et al., 2017). Therefore, there is an increasing demand for environmentally friendly, cost-saving methods with high efficiencies of FOG removal to enable efficient industrial wastewater management (Lagos et al., 2023).

Challenges of Fats, Oils, and Grease (FOG) in Wastewater Treatment

Fats, oils, and grease (FOG) are considered one of the major pollutants in industrial wastewater, contributing to severe disturbances in wastewater treatment plants worldwide. The accumulation of FOG causes pipe clogging, reduces oxygen transfer efficiency, and increases the cost of maintenance. It has recently been estimated that FOG accounts for nearly 47% of sanitary sewer overflows in the US and over 50% of sewer blockages in the UK. The slow degradation rate of FOG in treatment processes leads to system overloading and poor quality. These issues point to an urgent need for effective and low-cost FOG treatment technologies (Organicabiotech 2025; Alibardi et al. 2025; Yusuf et al. 2025).

Treatment of FOG

Many methods for treating FOGs in industrial wastewater exist, including grease traps, skimmers, and chemicals that degrade or break the oil apart for removal (He et al., 2017). However, they can be fairly expensive, as well as hard to maintain, possibly creating other types of wastes that still must be cleaned up before disposal (Yusuf et al., 2023). Due to such problems, researchers have been in search of simpler, cheaper, and even safer methods of removing FOGs without harming the environment.

One approach gaining attention is the use of biochar, which is produced by heating agricultural organic waste such as banana peels in limited oxygen. This process creates a lightweight, porous carbon material that can adsorb FOG from

water (Urgel et al., 2024). Banana peel-derived biochar has a large surface area allowing more space for FOG molecules to attach, which improves its efficiency in treating oily wastewater (Channei et al., 2025). Turning banana peels into biochar is a smart and cheap way to reduce waste and at the same time keep industrial wastewater clean so it does not cause problems like clogged pipes or dirty rivers.

Small-scale biochar can be made without the use of expensive furnaces by using simple, low-cost techniques. A widely used process is slow pyrolysis, whereby banana peels are subjected to a temperature of 450–500 °C in a limited oxygen environment. A double barrel retort consists of a small metal drum placed inside a larger one. Burning wood in the outer drum heats the inner barrel to approximately 470 °C for three hours (Lamichhane et al., 2023).

Conventional and Emerging FOG Removal Technologies

Traditional removal methods mainly include saponification and skimming, these often result in incomplete removal, high energy use, and even secondary pollution. While bioremediation and advanced filtration appear promising, further-scale applications are yet to be widely realized, especially in resource-poor environments. In mitigation of environmental and economic impacts of FOG in wastewater, alternative sustainable measures will be required (Thakur et al., 2024; ProcessWerx, 2024).

Biochar as a Sustainable Adsorbent in Wastewater Treatment

Banana peels are one of the most abundant agro-industrial wastes that have gained attention as feedstock for the production of biochar because of their high carbon content and porosity. Banana peel biochars from the latest experiments are characterized with a high surface area of ~114 m²/g and an excellent adsorption capacity for organic pollutants such as bisphenol-A and dyes. Biochar from banana peels is prepared by pyrolysis around 600°C under inert atmospheres, optimizing the structure for contaminant removal. The valorization of waste in banana peels addresses not only pollution but also agricultural management (Ud Din et al., 2025; Kazmi et al., 2025; Biobased Diesel, 2024).

Banana Peel Biochar as Treatment of Wastes

The banana peel biochar demonstrates strong potential for treating dirty water with its porous structure and natural capability for absorption of harmful substances. It has been proven capable of the removal of heavy metals and dyes from water. These features have made it a very useful and eco-friendly material for waste treatment in places where banana waste is common (Kizito et al., 2015).

The efficiency of banana peel biochar has also been tested for the removal of FOG in industrial wastewater by adsorption. Under optimum pH, contact time, and dosage conditions, it captured up to 90% of oily contaminants during laboratory tests. With its high removal efficiency, banana peel biochar is considered a promising,

environment-friendly solution to treat oil-laden effluents from industrial facilities, particularly where conventional oil-waste management is limited.

The pH of the solution is another important factor that affects the adsorption performance of biochar because it alters the surface charge of the biochar and the behavior of contaminants. In most adsorption studies, pH is a variable of interest, but in this study, it will not be varied. Instead, natural pH will be measured and reported for all collected wastewater so that the effect of biochar dosage on FOG removal can be evaluated more clearly.

In most laboratory experiments, pH is adjusted using analytical-grade hydrochloric acid and sodium hydroxide. This adjustment of pH allows the researcher to mimic, understand, and obtain insight into the performance of biochar under acidic, neutral, and basic conditions while developing methods for actual wastewater treatment (Mohan et al., 2014). Among the available banana varieties, Cavendish banana peels have been one of the frequently used raw materials in biochar production due to their high availability, relatively uniform chemical composition, and favorable properties for consistently producing high-quality biochars with greatly enhanced adsorption capacity for water contaminants (Al-Sareji et al., 2024).

Among the varieties available, Cavendish banana peels were chosen for this study for the production of biochar, due to practical and scientific considerations. Cavendish bananas (*Musa acuminata*) are widely cultivated and exported and dominate the production of bananas in the Davao region, especially in Tagum City of the Philippines, where this research was conducted. The large quantity of Cavendish banana waste available from post-harvest packing facilities in Madaum, Tagum City, provided easy access to a continuous supply of reasonably priced raw materials appropriate for this study. Scientifically, Cavendish banana peels have been frequently used in biochar production research relating to the production of biochar because they have a relatively uniform chemical composition, a high carbon content, and favorable structural properties, with a consistent production of high quality biochars (Al-Sareji et al., 2024). This makes them a suitable feedstock for developing practical wastewater treatment systems that are replicable and predictable in performance.

Gaps and Opportunities for Practical Application

Despite promising laboratory-scale results, few studies have been conducted using real industrial wastewater or in gravity-fed prototype setups. Most studies point to the need for research focused on operational feasibility, scalability, and long-term performance in diverse local conditions. This gap provides a key motivation for the current research emphasis on practicality, accessibility, and sustainability in wastewater treatment applications, especially within developing regions where banana waste is so abundant (Fang et al., 2025).

Pebble Pre-filter and Flow Distribution

A layer of pebbles above the biochar serves as a coarse prefilter and flow distributor. The pebble layer reduces localized channeling, traps large debris, and spreads incoming flow evenly across the biochar bed, which helps maximize the effective contact area in a gravity-fed prototype. (Veolia Water Technologies, n.d.)

Parameters To be Studied

To help guide the prototype design and evaluate feasibility, key factors such as biochar dosage, bed depth, and particle size should be examined using literature benchmarks and prototype observations (Urgel et al., 2024).

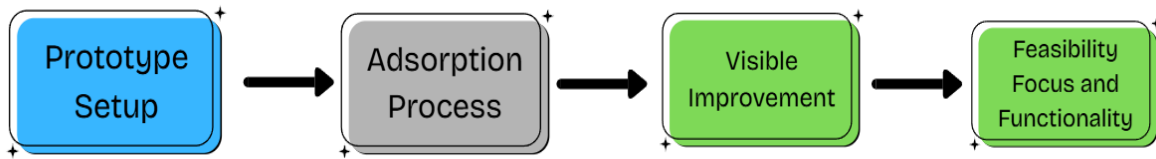
Synthesis

Banana peels can be transformed into highly porous, carbon-rich biochar through slow pyrolysis in an oxygen-limited double-barrel retort system. The resulting biochar has surface properties that attract and trap fats, oils, and grease. Based on previous studies and observation of the prototype, this study checks the amount of biochar and length of time the Industrial wastewater stays inside the filter bed to see if it impacts FOG capture and helps choose the proper prototype size. The biochar is packed into a vertical filtration tube. Wastewater is poured at the top and flows downward through the biochar by gravity and as it does, the grease attaches to the pores of the biochar, with cleaner water exiting at the bottom of the setup. Low-cost to set up, this simple system may offer a practical means of significantly reducing FOG pollution in industrial wastewater.

Theoretical Framework

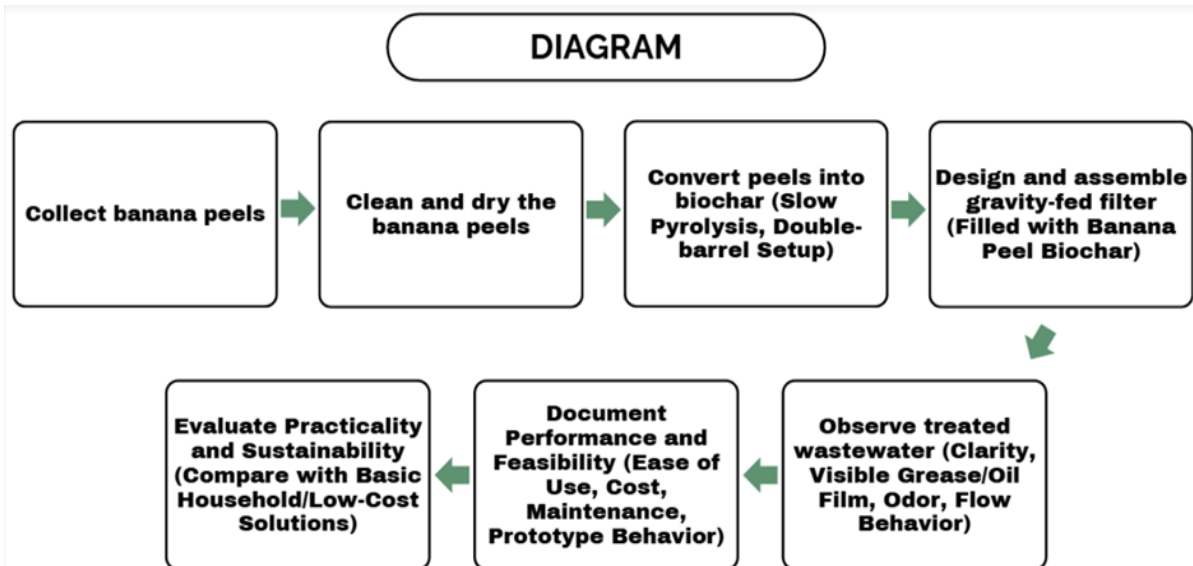
This research is based on the scientific principle of adsorption, where FOG attaches to the surface of a solid material. Banana peels, when transformed into biochar via slow pyrolysis, form a structure that becomes porous and carbon-rich, thus creating many surface sites for FOG molecules to attach themselves to (Urgel et al. 2024). These pores, alongside the surface functional groups, enhance the potential of biochar to hold oily substances from wastewater. From an engineering point of view, this study applies adsorption through a gravity-fed filtration prototype. The focus is on checking whether the biochar can be arranged and packed in a way that allows proper contact between the wastewater and the filter bed. Factors such as flow path, contact time, and filter packing are considered to make sure that the wastewater stays long enough in the biochar for adsorption to take place. This framework connects the scientific basis of adsorption with a practical prototype design that is low-cost, community-friendly, and suitable for small-scale industrial wastewater management (Wang et al., 2024).

Figure 1. Diagram of the prototype adsorption process.



Conceptual framework showing the process flow of the study. The banana peel biochar filtration prototype adsorbs fats, oils, and grease (FOG) from industrial wastewater, resulting in visible improvement of water quality. The final stage highlights that the study focuses on feasibility demonstration.

Figure 2. Diagram of the whole methodology process



Hypothesis and Objectives

Hypothesis

This study assumes that if banana peel biochar is used inside a filtration prototype, then it will improve the condition of industrial wastewater by adsorbing fats, oils, and grease (FOG). Because of its porous structure and surface functional groups, the biochar is expected to show visible improvement in water quality, indicating its potential for FOG reduction.

1. If banana peel biochar is applied to industrial wastewater, then the visible presence of fats, oils, and grease (FOG) will be reduced, showing that the prototype is effective as a low-cost filtration material.

Objectives

This research aims to demonstrate the feasibility of using banana peel-derived biochar in a filtration setup for industrial wastewater treatment. Specifically, it seeks to:

1. To construct a low-cost filtration prototype using banana peel-derived biochar.
2. To demonstrate the prototype's ability to visibly improve the appearance of industrial wastewater (reduced surface grease, improved clarity).
3. To assess the prototype's practical potential for reducing FOG in real-world settings.

2. METHODOLOGY

2.1. Collection and Preparation of Materials

2.1.1. Sourcing of Banana Peels

For this study, banana peels were collected from the packing area in Madaum, Tagum City, Davao del Norte, Philippines. This area is highly recognized for having large Cavendish banana plantations and is considered one of the biggest banana-producing areas in the Philippines. More precisely, 2 bundles of unripe Cavendish banana peels were obtained from the post-harvest processing and packing facilities where bananas are cleaned, sorted, and prepared for distribution. The bananas collected were washed to remove dirt and residues before proceeding to biochar production.



Image 1. Unripe Cavendish (*Musa acuminata*) bananas.

2.1.2. Collection of Wastewater Samples

Samples of wastewater were collected from the canals and drainage systems around the main areas of the food processing industries in Davao City, including those near the Anflo Industrial Estate in Panabo City, the Food Processing Innovation Center area, and the Calinan and Agdao districts. These are strategic places to source samples of typical industrial wastewater contaminated with FOG, since various food manufacturing and processing companies are within these places. Collected samples were stored in appropriate containers, and transportation was carried out under controlled conditions.



Image 2. Industrial Wastewater collected from Davao City

2.1.3. Additional Materials

Additional materials for the study were sourced from various practical locations: pebbles were collected at outdoor areas near their homes, the PVC tube was provided by the research consultant, while the mesh filter and duct tape were bought from nearby sari-sari stores. Additional materials like the handheld infrared (non-contact) thermometer, tire wire, PVC cutter, and extra duct tape were supplied by the families of the researchers. Barrels used in the biochar pyrolysis process were bought at a nearby shop. This combination reflects the resourceful and accessible approach taken in building the prototype and conducting the study.



Image 3. Pebbles collected outside the researchers' homes



Image 4. Pebbles being washed thoroughly



Image 5. *PVC Tube used for filtration*



Image 6. *Barrels for Double-Barrel Retort System Pyrolysis*

2.2 Synthesis of Banana Peel Biochar

2.2.1. Pre-treatment of Banana Peel Biochar

Unripe Cavendish banana peels were gathered, cut into smaller pieces, and washed to rid them of any soil or filth particles. The prepared peels were naturally dried in sunlight for five (5) days. This drying step is necessary to prepare the biomass for the pyrolysis process by lowering its water content in order to improve efficiency in pyrolysis and produce higher quality biochar.



Image 7. Sliced Unripe (*Musa acuminata*) cavendish banana peels



Image 8. Sliced Unripe (*Musa acuminata*) cavendish banana peels that was left to dry for 5 days

2.2.2 Pyrolysis Procedure

The biochar was produced through the process of slow pyrolysis of dried banana peels in a double barrel retort system. Dried peels, which were put inside the inner barrel, were heated with firewood put inside the outer barrel at a temperature of about 470° to 500°C, temperatures were monitored with a handheld infrared (non-contact) thermometer for three hours in an oxygen-limited environment. This controlled thermal decomposition promotes the breaking down of organic material into porous carbon-rich biochar with high surface area and adsorption capacity. The banana peel biochar, after pyrolysis, was allowed to cool before being collected, ground, and kept inside airtight containers for subsequent use in filtration experiments.



Image 9. Setting up Double Barrel Retort System



Image 10. Pyrolyzation of Banana Peel Biochar



Image 11. *Banana Peel Biochar*

2.3 Prototype Filtration Column Design and Preparation

A 5.1 foot-long (155.45 cm) PVC tube was cut to 3.5 feet (106.68 cm) in length and then split into two equal segments, each 1.75 feet (53.34 cm) long. When in use, the segments are joined back together to form the full filtration column. A fine mesh filter was attached to the top opening of the top segment using tire wire cinched tightly around the tube rim. Tire wire was then wrapped around the joint at which the top and bottom segments were joined for structural integrity; duct tape wrapped over that joint serves as a seal.

Filtration media are packed from the inlet, or top, of the column to the outlet, or bottom, in the following sequence: a pebble layer in the top segment serves as a coarse pre-filter and flow distributor. A mesh filter is placed below the pebbles to prevent the pebbles' migration into the bed of biochar. Banana peel biochar is densely packed into the bottom segment as the primary adsorbent material of this filter. This provides effective filtration because there is a high degree of contact between the wastewater and the biochar.



Image 12. *Cutting PVC tube into segments*



Image 13. *Assembling PVC tube*

2.4 Experimental Procedure

The filtration experiment was conducted once using the assembled prototype filtration column. A total of 250 milliliters, measured and equivalent to one-fourth of a 1000 milliliter mineral water bottle, was poured at the top of the column, with gravity driving the filtration process through the pebble layer, mesh, and biochar bed. The treated water was collected at the outlet for observation and analysis. This single trial served as a feasibility demonstration to assess the functional capability of the banana peel biochar filtration prototype.



Image 13. *Putting Industrial wastewater in the filtration tube*

2.5 Observation, Data Collection, and Analysis

The clarity, presence of visible oil films, scum, and sediment were visibly observed in the filtered treated wastewater. Photographic documentation was made to support qualitative observations. Data collection was focused on the recording of these visible parameters, which were noted in an observation log sheet. Considering that this is an exploratory study, analysis will emphasize a comparative approach to assess the efficiency of the banana peel biochar prototype through comparison of the before and after appearances.

2.6 Safety and Waste Disposal

All safety procedures, including protection against biological and chemical hazards due to wastewater sample handling, were done during the research study. Wastewater samples were managed at all times with personal protective equipment to avoid coming into contact with potentially infectious materials, for example, gloves. Basic hygiene practices were adopted and washing of hands after sample handling. The wastewater and spent biochar generated in this study were collected and disposed of in accordance with local environmental legislation to ensure environmentally benign and safe management of possibly hazardous materials. Equipment and materials used in all the experiments have been properly cleaned and sanitized; hence, the risk of cross-contamination is reduced.

3. RESULTS AND DISCUSSION

3.1 Visual and Physical Assessment

This section presents the results from the prototype gravity-fed filtration of industrial wastewater using banana-peel biochar. It highlights visual and sensory (odor) changes observed before and after treatment, interprets qualitative indications of contaminant removal, and clearly states the study's limitations according to the methods used. The section also discusses practical implications and offers evidence-based recommendations for future optimization.



Figure 1. Before and after photos of industrial wastewater samples treated with banana-peel biochar filtration tube prototype.

The treatment performance of the banana-peel biochar filtration tube was assessed through visual and sensory inspection of industrial wastewater samples before and after filtration, as demonstrated in Figure 1.

The first wastewater sample, represented by the left bottle in Figure 1, was cloudy vibrant brown and contained suspended particulates, it had a strong, rotten smell that was described as "rotten and disgusting." After the single-pass filtration through the banana-peel biochar prototype, the output sample represented by the right bottle in Figure 1 was visibly clearer with lighter color and fewer suspended particles. Compared to the initial sample, the surface oil film were highly reduced and not as visible in the filtered water. A change in odor was observed, the filtered sample was described as practically odorless, whereas the initial sample was strongly odorous. Finally, the banana-peel biochar appeared darker after use, indicative of adsorption and retention of pollutants.

3.2 COMPARATIVE ANALYSIS

Table 1. Observations and Interpretations of Banana-Peel Biochar Filtration Performance

Observations	Interpretation
Cloudy, vibrant brown, odorous input water	High FOG, polluted, dissolved waste
Clearer, lighter, odorless	Removal/adsorption of most FOG and solids
Sediment at bottom of filtrate bottle	Partial filtration, Heavy FOG was removed.
Surface film reduced	Biochar adsorbed most of FOG, reducing oil layer
Darkened liquid with biochar after use	Pollutant capture by pore structure

Observations describe conditions before and after filtration, showing how the treatment affected wastewater quality.

These observations such as clarity increase, reduced surface film, and darkened spent biochar indicate that practical design choices, such as greater bed depth and slower flow, are likely to increase visible FOG capture. This study only used a single test configuration and did not measure dose-response or laboratory FOG concentrations, controlled dosage trials are needed to quantify optimal biochar amounts and contact times.

3.3 DISCUSSION

The visual results from the demonstration indicate that banana-peel biochar inside a gravity-fed tube can visibly improve the clarity and appearance of industrial wastewater, consistent with the hypotheses in the proposal. The removal of turbidity and the reduction of the oily film are qualitative evidence that adsorptive and filtering processes took place within the prototype.

Based on the prototype demonstration, it is recommended to prioritize a properly distributed inlet pebble layer and a deeper biochar bed to increase contact time. These are supported both by the visual improvements observed during the tests and by adsorption theory, numeric recommendations would require follow-up tests that vary bed depth and flow rate.

3.4 MECHANISMS

As described in the manuscript, banana-peel biochar has a highly porous, carbon-rich internal structure. This gives it a large surface area and many functional groups that attract and trap fats, oils, grease, and particulates from water. Contaminants in the wastewater likely adsorbed onto the biochar's surfaces as the water moved through the packed bed in the filtration tube. Particles and oil droplets were physically captured in the pores or coated onto the surface, as suggested by the change in both clarity and difficulty observing oil films in the filtrate. This

mechanism matches the adsorption and pore-capture phenomena reported in literature cited in the manuscript (Urgel et al., 2024; Mohan et al., 2014).

Compared to laboratory setups, the prototype test used unoptimized field conditions and industrial-strength wastewater, which may be more difficult to treat than typical lab samples. Still, the clear reduction in visible contaminants suggests that banana-peel biochar has practical potential for rough treatment or pre-treatment at low cost, supporting claims in the manuscript and related literature (e.g., Channei et al., 2025).

Practical Implications:

This method uses waste banana peels to produce a useful water treatment medium. It offers a sustainable, low-cost alternative. Especially in banana-producing regions and the prototype's gravity-fed design needs no electricity or complex equipment. This could be replicated in community-based or small-scale industrial settings. However, practical implementation would require scaling up, routine waste handling, and monitoring if used routinely.

3.5 LIMITATIONS

- Single prototype trial: Only one demonstration was performed.
- The oil/grease assessment relies on observable changes rather than chemical analysis.
- Uncontrolled variables: Field wastewater samples can vary greatly in contaminant load.
- No statistical testing: Only qualitative changes were observed.
- Short-term observation: No data on long-term filter performance, clogging, or cleaning cycles.

4. CONCLUSION

The prototype gravity-fed filtration tube packed with banana-peel biochar visibly improved clarity and general appearance of industrial wastewater during a single demonstration. The most noticeable differences were visual and in odor, the filtered water was clearer, lighter in color, and practically odorless compared to the raw input. These observations suggest that banana-peel biochar was able to adsorb and retain fats, oils, and grease present in the wastewater. However, no laboratory data or chemical quantification was collected from this study in order to measure the removal efficiency of these pollutants or their actual concentration. Besides, the demonstration was qualitatively conducted once, which constrains generalizing findings or statistically validating the efficacy of the prototype. Consequently, future research should give priority to rigorous testing of FOG and other parameters of water quality before and after treatment in the laboratory. Several replicate trials are needed to confirm reproducibility and allow for optimization in the filtration system's design and performance. Full characterization of the banana-peel biochar adsorption capacity and long-term use effects must be carried out to assess filter lifespan and regeneration potential. In general, all these next steps are fundamental toward scientific confirmation scaling up of this low-cost, sustainable water treatment technology for practical real-world applications.

5. RECOMMENDATIONS

Based on the findings and limitations of this study, the following recommendations are suggested for further work and practical implementation:

1. **Laboratory Quantification:** Conduct proper laboratory tests to quantify the FOG concentrations before and after biochar filtration to establish the removal efficiencies and performance metrics.
2. **Multiple Trials:** Replicate experiments in a controlled environment to verify reproducibility, optimal dosage of biochar, and the impact of operational parameters such as flow rate and contact time.
3. **Filter Design Optimization:** Biochar particle size, bed depth, and pre-filter material will be studied further for their effects on the effectiveness of filtration and clogging rate with a goal in enhancing stability in the prototype.
4. **Long-term performance:** Study the life span and regeneration capacity of banana-peel biochar to evaluate its practical applicability and cost-effectiveness in relation to continuous industrial wastewater treatment.
5. **Evaluation Under Varying FOG Loads:** Testing the filtration systems on wider industrial wastewater types with different FOG loads will give a better insight to broader applicability and limitations.
6. **Scaling and Field Trials:** Develop larger-scale prototypes, conduct field trials in industrial settings, especially in regions with abundant banana waste, in order to assess real-world feasibility as well as operational challenges.
7. **Environmental and Economic Assessment:** Assess the environmental impact and cost-benefit balance of using banana peel biochar compared to conventional methods of FOG treatment to aid in decision-making for implementation.
8. **Practical Design Improvements:** Increase the depth of the bed and maintain slow, gravity-fed flow to assure longer contact time between wastewater and the biochar. Future work should test different bed depths and flow rates to identify the most effective configuration.

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