Developing of a Multi-Layered 3D-Printed Filtration System

Utilizing Natural Coagulants and Bio Adsorbents for Potable Water Access

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ABSTRACT

Access to clean water remains a global crisis, as around 2 billion people currently lack safe drinking water. This leads to people having to consume water contaminated with deadly pathogens, leading to around 1.7 million annual deaths. To address this problem, this research consisted of developing a cost effective, 3D-printed bio-filter using natural coagulants that will be able to filter bacteria and other contaminants from dirty water.

The methods include utilizing a multi-layered filtration assembly designed in Fusion 360 and produced via 3D printing. The filtration media consisted of moringa seed powder ground into biodegradable tea bags and pebbles. These pebbles were coated in a chitosan-acetic acid solution and stabilized using sodium tripolyphosphate before being oven dried. The 3D structure featured three compartments for these media, each with central flow holes, and a final collection chamber at the base equipped with a discharge outlet to facilitate sequential purification.

The results show that the 3D-printed bio-filter is incredibly effective, successfully clearing out nearly all the methylene blue. Across our test samples, the filtration results were highly significant, with a p-value under 0.05. Both versions of the filter performed exceptionally well, removing almost all contaminants even at higher concentrations. These findings suggest that combining moringa and chitosan in a 3D-printed design offers a promising way to create potable water.

Key words: potability, contaminated water, natural coagulants

RATIONALE

Do people really have to be forced to suffer because of contaminated water? Potable water should be a basic human right, not something only the fortunate and entitled to have. Approximately 2 billion people cannot have access to clean and safe drinking water. Their only choice is to drink water that has been contaminated with deadly bacteria and disease. This has led to around 1.7 million people dying every year, 900,000 of which are children under the age of 5. Is this really the world you want to live in? A world where children are denied their basic need for clean water? This is not something that should be allowed, especially when there are places around the world with an abundance of uncontaminated water.

This research aims to create a 3D printed bio filter that is replicable, cost effective, and can filter out anything you put into it. In this project we will use moringa seed powder, chitosan, and pebbles to filter out bacteria and other harmful chemicals out of the water. This bio filter will be tested on multiple different sources of contaminated water.

BACKGROUND RESEARCH

Water Access

Access to clean and safe drinking water remains a significant global challenge, despite recent improvements. Between 2015 and 2024, approximately 961 million people gained access to safely managed drinking water services, increasing global coverage from 68% to 74% (UNICEF, 2024). However, as of 2024, an estimated 2.2 billion people still lacked access to safely managed drinking water, while 3.4 billion lacked safely managed sanitation and 1.7 billion were without basic hygiene services at home (United Nations, 2024). These deficiencies not only jeopardize public health but also hinder sustainable development. Proper water management is essential for

ensuring food and energy security, protecting biodiversity, and mitigating the effects of climate change (United Nations, 2024).

The lack of access to safe water is a critical public health issue. According to the World Health Organization (2024), unsafe drinking water, inadequate sanitation, and poor hygiene practices contribute to around one million deaths from diarrheal diseases each year. Our World in Data (2024) further emphasizes that one in four people worldwide still lack access to safe drinking water, with contaminated water sources responsible for more than a million deaths annually. These alarming statistics highlight the urgent need for global action to improve water safety and sanitation infrastructure to prevent waterborne illnesses and save lives.

What Is Moringa Seed Powder and How Will It Help?

Natural plant extracts have been used for water purification for centuries, particularly in communities lacking access to advanced treatment technologies. One such plant, *Moringa oleifera*, has shown significant potential due to its coagulative and antimicrobial properties. In recent studies, *Moringa oleifera* seed powder has been effectively applied to treat greywater in regions such as the Upper East Region of Ghana. When used in combination with sand filtration, *Moringa* treatment resulted in substantial reductions in turbidity (98.14%), total suspended solids (98.9%), and microbial contaminants such as *E. coli* and total coliforms (>99%) (Amoah et al., 2020). While most treated water parameters improved and met World Health Organization (WHO) standards for drinking water, the biological oxygen demand (BOD) unexpectedly increased, possibly due to the organic content of the Moringa seeds used (Amoah et al., 2020).

These findings suggest that while *Moringa oleifera* is highly effective in improving water quality, system design and treatment conditions must be optimized for best results.

Beyond its use in water treatment, *Moringa oleifera* is widely recognized for its medicinal and antimicrobial properties. Moringa powder has been found effective in sterilizing contaminated surfaces and combating a broad spectrum of bacteria and fungi, including strains associated with gastrointestinal illnesses (WebMD, 2024). Its application has extended to wastewater treatment, where studies have demonstrated high efficacy in reducing turbidity (up to 99.5%), color (97.7%), and chemical oxygen demand (COD) (65.82%) in both acidic and basic wastewaters (Al-Gheethi et al., 2021). These combined antimicrobial and coagulative properties highlight *Moringa oleifera* as a promising low-cost, sustainable alternative to chemical coagulants in water and wastewater treatment processes, particularly in resource-limited settings.

The use of chitosan as a natural coagulant

Chitosan, a naturally derived biopolymer obtained from chitin found in the shells of crustaceans such as shrimp and crabs, has emerged as a highly valuable material across multiple industries due to its unique chemical and biological properties (Rinaudo, 2006). With characteristics such as non-toxicity, biodegradability, biocompatibility, and mucoadhesiveness, chitosan has been widely explored in biomedical fields, especially in tissue engineering and drug delivery systems (Bernkop-Schnürch & Dünnhaupt, 2012). Its ability to form gels and films, along with its antibacterial and antifungal capabilities, make it particularly appealing for applications that require controlled release or structural support for cellular growth

(ScienceDirect, 2024). These properties continue to inspire new innovations in both academic research and industrial product development.

In environmental engineering, chitosan has demonstrated significant potential in water purification systems. When introduced to contaminated water, chitosan acts as a natural coagulant, binding to small particles and pollutants, which can then be more easily removed through filtration (Washington Stormwater LLC, 2024). This eco-friendly and non-toxic method is particularly useful in stormwater treatment systems where effective pollutant removal is essential for protecting aquatic ecosystems. The use of chitosan-enhanced sand filtration, for example, has proven to increase filtration efficiency and produce cleaner effluents, contributing to more sustainable wastewater management practices (Washington Stormwater LLC, 2024). Its effectiveness, sustainability, and accessibility position chitosan as a promising alternative to conventional synthetic coagulants.

STATEMENT OF THE PROBLEM

General Problem

This research aims to engineer a 3D printed water bio filter to improve the quality of contaminated water.

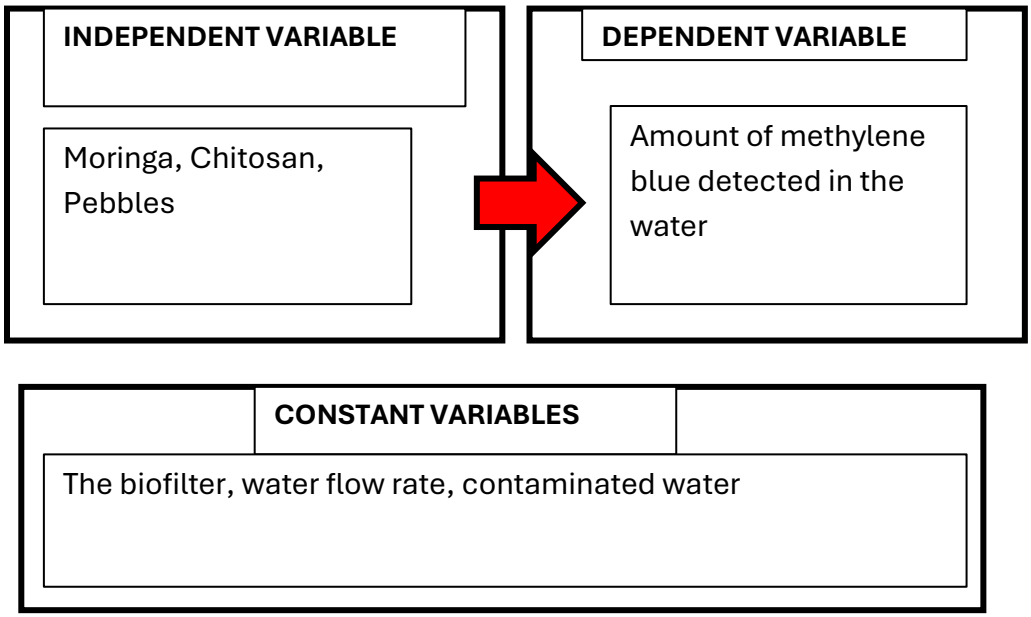
Specific Problem

1. Does the engineered 3D bio filter help with removing methylene blue from contaminated water?
2. Does the dose of moringa affect the efficiency of the engineered bio filter in bioremediating the methylene blue from the contaminated water?

Hypothesis

If water is passed through the 3D printed bio-filter, then the level of dangerous contaminants will be reduced to concentrations safe for human consumption because the moringa, chitosan, and pebbles will serve as natural coagulants to filter out the contaminants from the contaminated water.

VARIABLES OF THE STUDY



METHODS

Preparation of Moringa (Moringa oleifera) Seed Powder for Water Purification Applications

The inner kernel of Moringa oleifera seeds were utilized for water purification purposes. Initially, the seeds were manually extracted from their pods, after which the kernels were finely ground using an electric grinder to obtain a uniform powder. The resulting fine powder was subsequently packed into empty tea bags for use in subsequent water treatment experiments.

Figure 1: Moringa Powder Dispensed into Empty Tea Bags (Image taken by the student researcher, 2025)

Preparation of Chitosan-Coated Pebbles for Water Purification Applications

A chitosan solution was prepared by mixing 80 mL of distilled water with 20 mL of vinegar, followed by gentle stirring. Subsequently, 1.0 g of chitosan powder was gradually added to the mixture with continuous stirring until fully dispersed.

Pebbles were washed thoroughly with tap water until the rinse water was clear, then boiled for 10–15 minutes, rinsed with distilled water, and dried on a clean tray. The clean, dry pebbles were placed in a beaker and submerged in the prepared chitosan solution. The mixture was gently stirred to ensure uniform coating, and the pebbles were allowed to soak for 30–60 minutes.

A 1% sodium tripolyphosphate (STPP) solution was prepared by dissolving 1 g of STPP in 100 mL of distilled water. The chitosan-coated pebbles were drained using a strainer and immediately transferred into the STPP solution. The pebbles were soaked for 5–10 minutes under gentle stirring to facilitate cross-linking.

Following this, the pebbles were drained and briefly immersed in a dilute sodium bicarbonate solution (1 teaspoon per 100 mL of distilled water), then lightly rinsed with distilled water. Finally, the pebbles were spread on a tray and oven-dried at 50–60 °C for 1–2 hours. The dried pebbles were stored in a clean, sealed container until further use.

Figure 2: Pebbles Coated in Chitosan (Image taken by student researcher, 2025)

Design and Fabrication of a Multi-Layered 3D-Printed Water Filtration Assembly

A 3D model of a multi-layered water filtration assembly was designed using Fusion 360 software. The initial step involved creating a circular base, which was dimensioned according to

specifications. Three identical copies of this base were produced, each intended to serve as a compartment for the filtration material. A central hole was incorporated into each of these bases to allow water to flow through the filtration media.

A fourth layer was designed as a collection chamber for the filtered water, featuring a small outlet hole on the side to enable water discharge. This multi-layered design facilitates sequential filtration and collection within a compact 3D-printed structure.

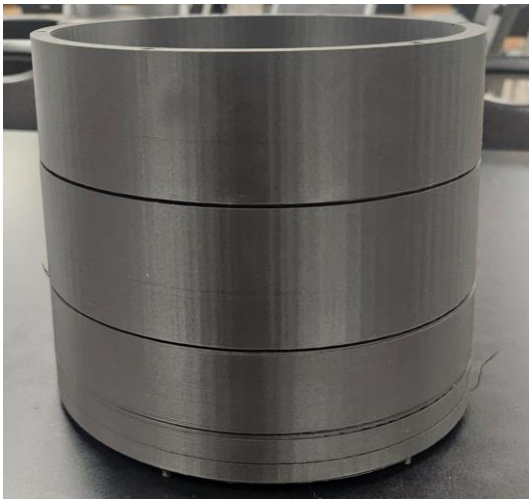


Figure 3: Multi-layered 3D Printed Filtration System (Image taken by student researcher, 2025)

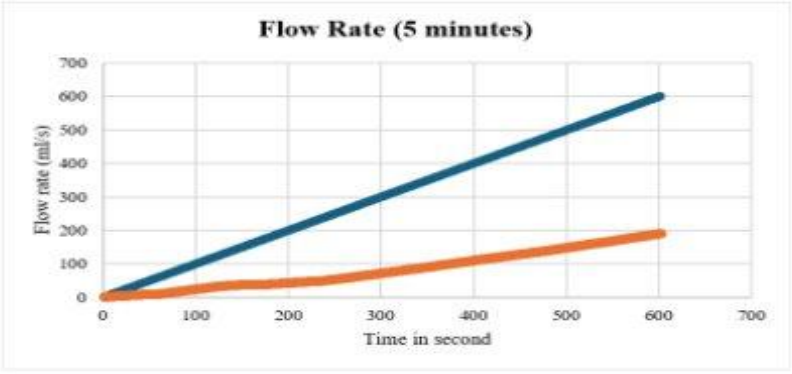
Analysis of Methylene Blue Concentrations and Contamination

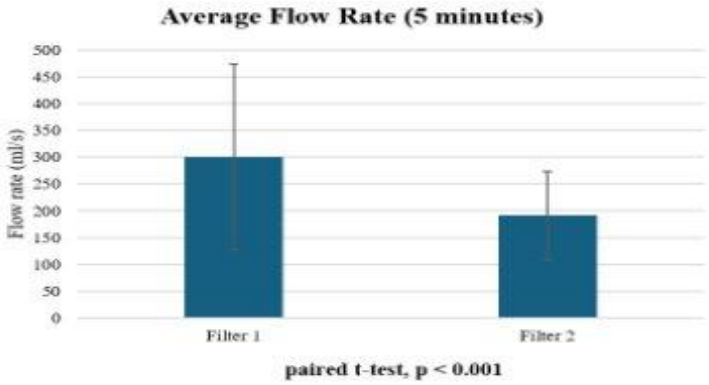
The initial step involved determining the absorbance wavelength of methylene blue. Subsequently, aliquots of 2 µL, 4 µL, 6 µL, 8 µL, and 10 µL of methylene blue were each added to separate tubes and diluted with distilled water to a final volume of 5 mL. The resulting solutions were then analyzed to assess the degree of contamination in each sample. The contamination level in each vial was subsequently measured using a UV–Vis spectrophotometer.

Figure 4: Aliquots Of Methylene Blue Added to Distilled Water to Make 5mL (Image taken by the student researcher, 2025)

Results

Flow Rate Analysis





Empty Bed Contact Time Analysis

EBCT is the average amount of time water stays inside the filter and is in contact with the filter media.

To calculate the EBCT, we need to consider the geometry of the filter

Filter Diameter= 19.81 cm
Filter Height= 19.7 cm

Finding the Cross-Sectional Area:

$A=\pi r^2$

$\pi(9.905)2=$ **308.2 cm²**

Finding the Bed Volume:

$V_b=A\times h$

$=308.2\times19.7=$ **6060 mL**

$$EBCT = \frac{V_b}{Q}$$

V_b= Bed Volume
Q= Flow rate

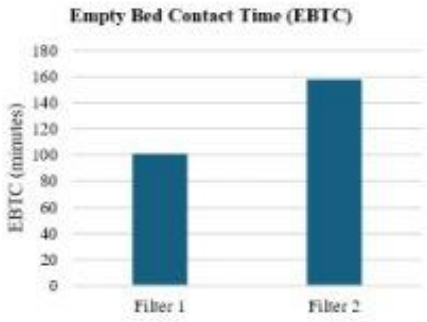
Q= V/t
V= volume collected
t= time

$$Q_1 = \frac{600}{300} = 2.00\ mL/s$$

$$Q_2 = \frac{190.92\ mL}{300\ s} = 0.636\ mL/s$$

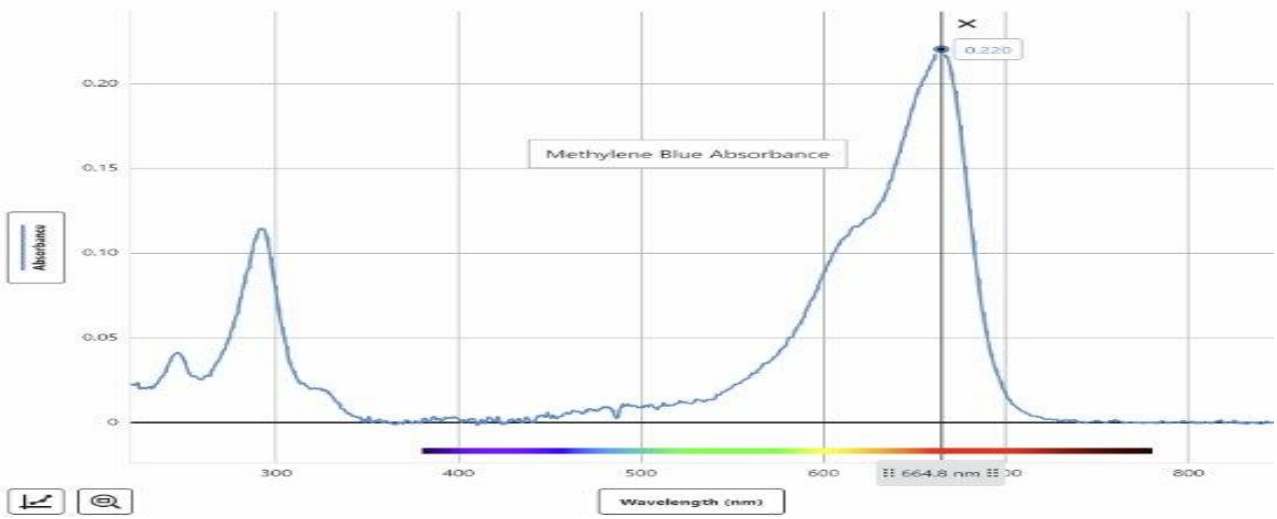
$$EBCT_1 = \frac{6060}{2.00} = 3030\ s = 50.5\ min$$

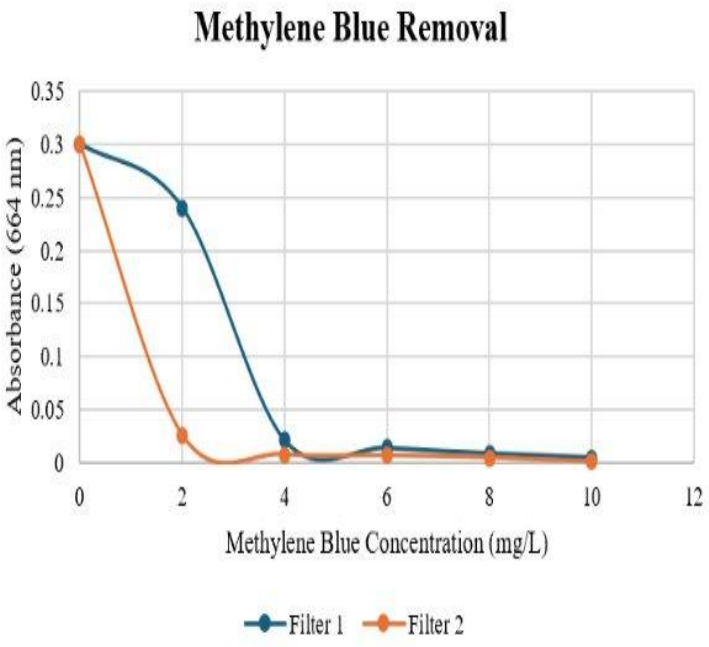
$$EBCT_2 = \frac{6060}{0.635} \approx 9543\ s = 159\ min$$

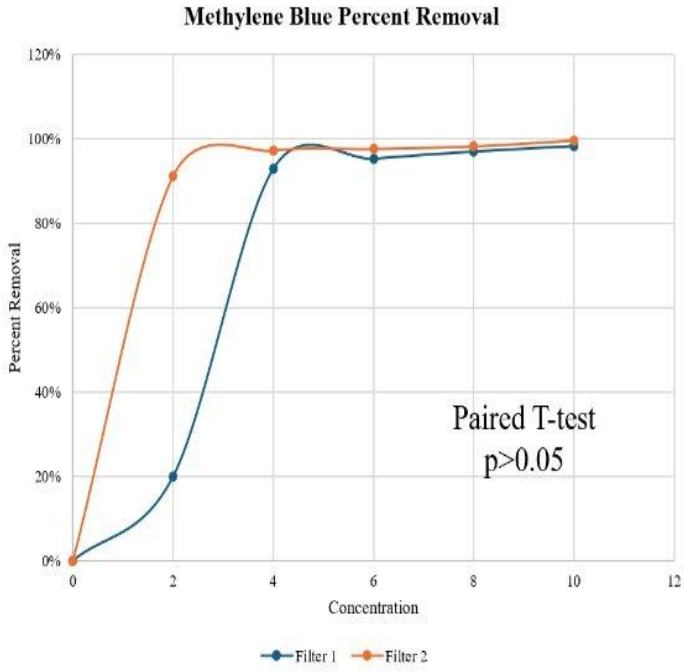


Filter 2 exhibited a higher empty bed contact time due to its lower flow rate, indicating that water remained in contact with the filtration media for a longer period. Increased EBCT is expected to enhance methylene blue adsorption efficiency.

Methylene Removal







DISCUSSION

The initial assessment of the hydraulic performance, as indicated by the cumulative flow curves, demonstrated stable and consistent gravity-driven flow for both filters. The linear increase in flow over time indicates reliability in both systems under test conditions. A clear distinction emerged, however, in the flow rate itself. Filter 1 consistently exhibited a steeper slope in its cumulative flow curve, reflecting a higher flow rate compared to Filter 2. This difference was quantifiable and significant; the average flow rate over a five-minute period was markedly higher for Filter 1. A paired t-test confirmed the robustness of this observation, yielding a p-value of less than 0.001, which indicates the variance between the two filters was a direct result of the specific filter configuration rather than random experimental variation.

The project also evaluated the effectiveness of both filters in removing methylene blue dye from a solution, using absorbance measurements at 664 nm as a proxy for dye concentration. The results show a strong correlation between decreasing absorbance and increasing initial methylene blue concentration, confirming effective removal via adsorption or degradation mechanisms within both filter systems. Both filters demonstrated high efficiency, achieving near-complete removal of the dye by an initial concentration of 4 mg/L, at which point the solution absorbance approached zero. This suggests that the treatment process reaches a saturation point where almost all available dye molecules are captured or broken down, indicating strong overall treatment efficiency with 95-100% removal at higher concentrations.

Despite the significant differences in hydraulic flow rates, the filters exhibited a nearly identical performance in the capacity to remove methylene blue. A paired t-test on the percent removal data showed no significant difference between the two filters across all tested concentrations ($p > 0.05$). This suggests that while the physical configuration of Filter 1 allows

for a faster processing time for a given volume, both filters ultimately achieve the same high level of water purification effectiveness for this particular contaminant. The findings imply that both filter designs are effective for dye removal applications, but design choices will depend on whether flow rate or cost/simplicity of construction is the primary concern.

Conclusion

Both filters effectively removed methylene blue, achieving near-complete removal at higher concentrations despite differences in flow rate. These results indicate that the filtration system is efficient, and that removal performance is comparable between filters under the tested conditions.

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