Developing of a Multi-Layered3D-Printed Filtration System Utilizing Natural Coagulants and Bio Adsorbents for Potable Water Access

BACKGROUND RESEARCH & QUESTIONS

Water Access

Two billion people still lack the UN-mandated right to clean water, resulting in over a million yearly deaths and hindering global development.

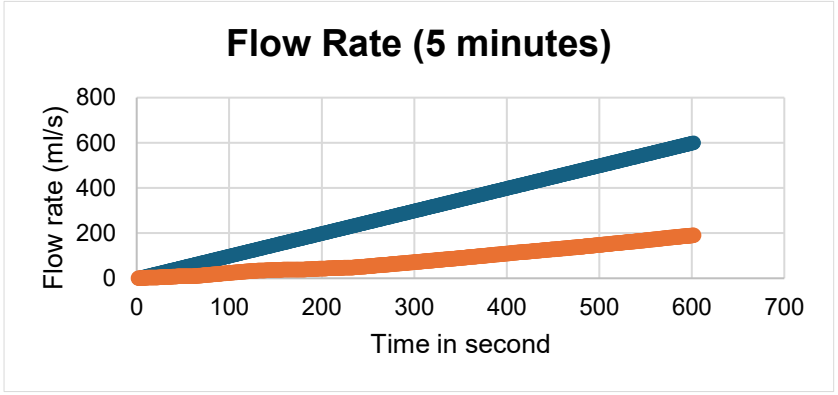
Natural Coagulants

Moringa seeds and shell-derived chitosan sustainably purify water by binding pollutants and killing microbes to provide safe drinking water.

Questions

- Does the engineered 3D-printed filtration system remove methylene blue from the water?
- Does the EBCT rate affect the rate of methylene blue removal?
- How does the initial methylene blue concentration affect percent removal efficiency?

DATA ANALYSIS AND RESULTS



Cumulative flow curves increased linearly, with Filter 1 maintaining a significantly higher flow rate than Filter 2. A paired t-test ($p<0.001$) confirmed that filter configuration statistically influenced these water output differences.

METHODOLOGY

Preparation of Moringa Filter

Moringa kernels were cleaned, shelled, ground into powder, filtered, and placed in a biodegradable tea bag.

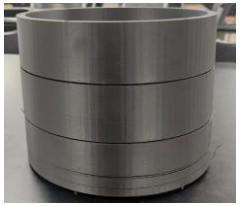
Preparation of Chitosan-Coated Pebbles

Meanwhile, pebbles were sterilized with hydrogen peroxide and boiling water to prepare them for coating. The pebbles were coated in a chitosan-acetic acid solution and then soaked in sodium tripolyphosphate to stabilize the layer. These coated pebbles were finished by drying in an incubator at 60 °C.

DISCUSSION AND CONCLUSION

Methylene Blue Removal

UV-Vis results showed a strong decrease in absorbance at 664 nm, and percent removal reached95–100% at concentrations ≥4 mg/L,



Empty Bed Contact Time

Filter 2's lower flow rate increased EBCT to 159 min, compared to 50.5 min for Filter 1.

My investigation revealed that:

The 3D-printed system achieved near-complete methylene blue removal, optimized by higher initial concentrations and longer contact times.

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Energy and Sustainability

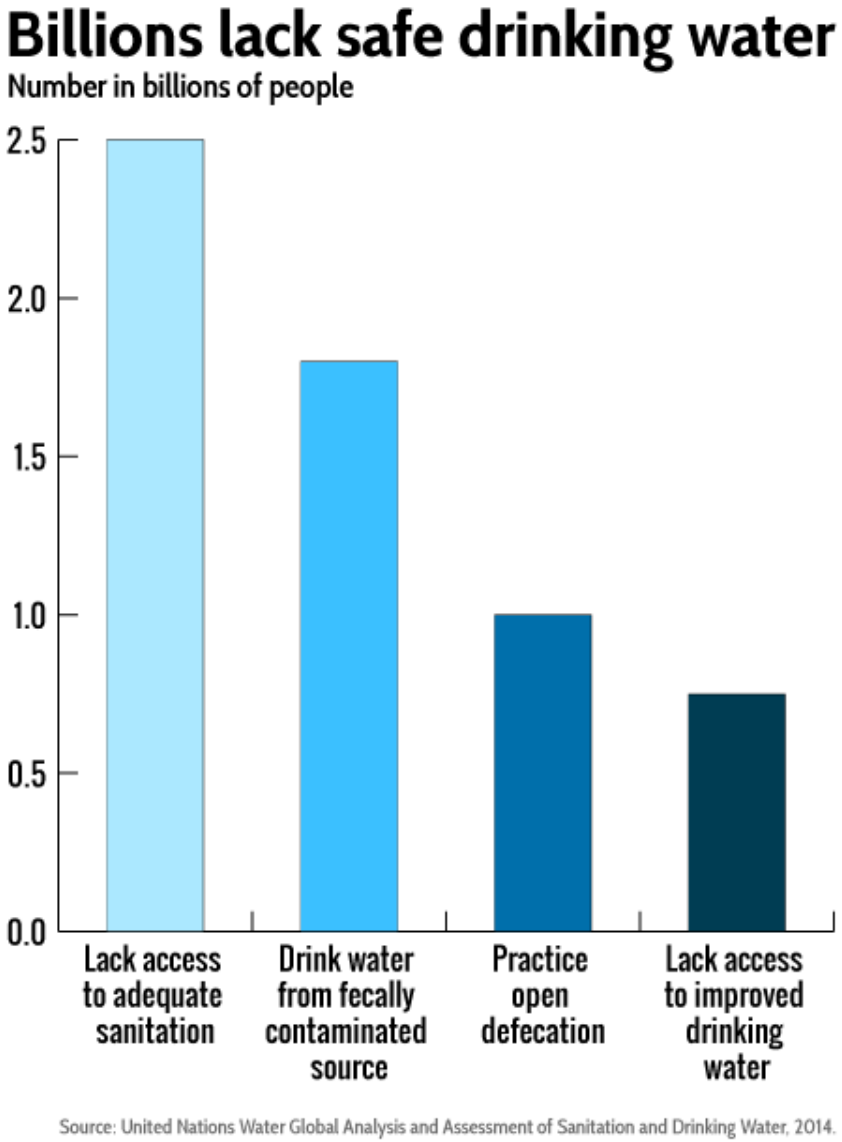
All photos and graphs were taken/created by the student researcher unless otherwise noted

Access to safe, potable water is a fundamental human right!

Global Water Access

- The United Nations established the basic human right of uncontaminated and potable water in 2010.
- Approximately 2 billion people have to drink polluted water.
- Around 1.7 million people die every year from impure water, 900,000 of which are children that do not even reach the age of 5.

Picture credit: https://mexiconewsdaily.com/mexico-living/the-natural-poisons-hidden-in-mexicos-groundwater/



Picture credit: https://ww.pbs.org/newshour/world/billions-people-safe-drinking-water-remains-reach

A World Thirsting for Change

According to UNICEF...

between 2015 and 2024,approximately **961 million** people gained access to safely managed drinking water services, increasing global coverage from 68% to 74%.

*But... how about the remaining **26-32%** who lack access to safe and clean drinking water?*

A Basic Human Right

Picture credit: https://www.indiatimes.com/news/india/by-2050-25-of-world-population-will-lack-access-to-clean-water-india-china-to-suffer-most-323313.html

Consequences

- Contaminated water sources are responsible for more than a million deaths annually.
- This jeopardizes not only public health, but also hinder sustainable development.

Natural Coagulants: A Possible Solution

Moringa

- Moringa oleifera seed powder has been effectively applied to treat greywater.
- Moringa seed powder is useful for cleaning turbid or contaminated water
- Moringa oleifera is widely recognized for its medicinal and antimicrobial properties.

Picture credit: https://plantigo.in/blogs/plant-based-protein-powders/10-incredible-health-benefits-of-moringa-seeds-you-didnt-know?srsltid=AfmBOoqXo6ZYVQiUAfh-bcQbzlNnUuGVgaopDHi_66x3O2eO6XLW_6T4

Chitosan

- Chitosan is a naturally derived biopolymer obtained from chitin found in the shells of crustaceans such as shrimp and crabs.
- When introduced to contaminated water, chitosan acts as a natural coagulant, binding to small particles and pollutants

Photo credit: https://www.hongdanaturals.com/knowledge/what-is-chitosan-powder

Project Inspiration

- For this project, I aspire to engineer a multi-layered bio-filter incorporated with natural coagulants to provide a cheap and easily accessible water filtration system to produce clean and potable water for areas with limited access.

Research Questions, Predictions, and Goals

Research Questions

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

Specifically, I aimed to answer the following questions:

- Does the engineered 3D-printed filtration system remove methylene blue from the water?
- Does the EBCT (Empty Bed Contact Time) rate affect the rate of methylene blue removal?
- How does the initial methylene blue concentration affect percent removal efficiency?

Predictions

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.

If the Empty Bed Contact Time (EBCT) increases, then methylene blue removal efficiency will increase, because longer contact time allows more dye molecules to interact with and bind to the filter media.

Engineering Goals

Goal 1: To engineer a multi-layer bio-filter to hold the natural coagulants.

Goal 2: Design and 3D print a filter with varying Empty Bed Contact Time (EBCT) rates.

Goal 3: Investigate the removal efficiency of the natural coagulants in removing methylene blue contamination.

Methods: Preparation of Moringa Kernels

1

Moringa kernels were selected, cleaned, and washed.

2

The outside shells of the moringa were removed before grinding.

3

The peeled moringa kernels were powdered using a coffee grinder.

4

The powder was filtered and placed inside a biodegradable tea bag.

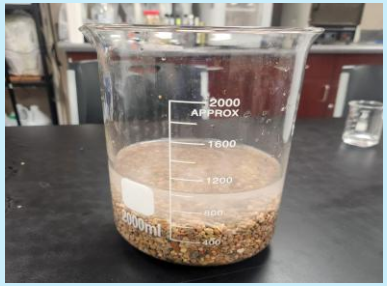
All photos taken by the student

Methods: Preparation of Chitosan-Coated Pebbles

1

Pebbles were washed in 3% hydrogen peroxide solution and boiled. Afterwards, the pebbles were rinsed in distilled water multiple times before pre-treatment

2



1 g of chitosan was dissolved in 1% acetic acid at 40 °C for 60 minutes.

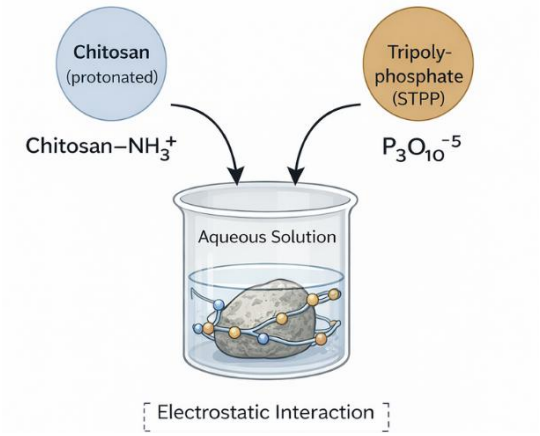
3

Dissolve 1 g of sodium tripolyphosphate (STPP) in 100 mL of distilled water to prepare a 1% solution, drain the chitosan-coated pebbles using a strainer, immediately transfer them into the solution, and soak for 5–10 minutes with gentle stirring to strengthen the chitosan coating and improve its water stability.

4

Dry the pebbles in a digital incubator at 60 °C for 60 to 120 minutes until dry.

Ionic Gelation Process

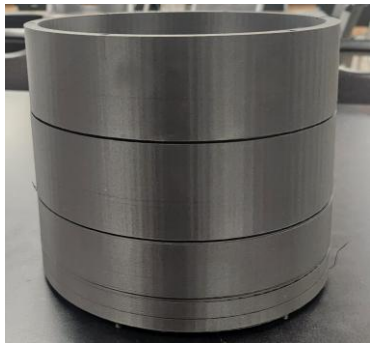


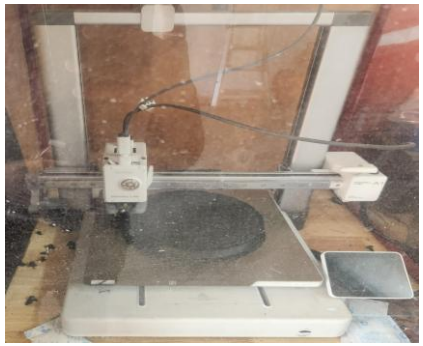
Ionic gelation occurs when positively charged chitosan (NH_3^+) electrostatically interacts with negatively charged tripolyphosphate ions ($P_3O_{10}^{5-}$), forming a cross-linked polymer network that coats the surface of the pebble.

All photos taken by the student

Diagram was generated using OpenAI

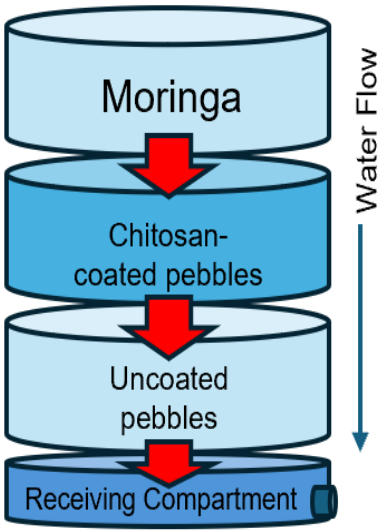
Methods: Design and Fabrication of a Multi-Layered 3D-Printed Water Filtration System





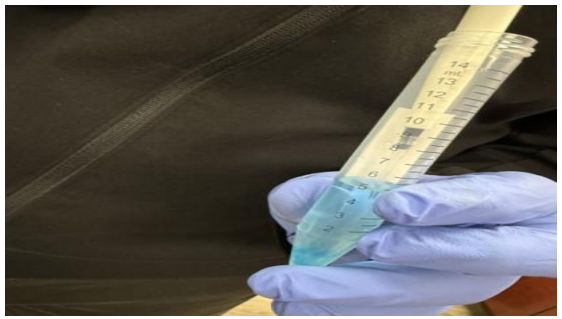
A multi-layered water filtration assembly was designed and fabricated using 3D printing, consisting of three vertically stacked compartments with centrally aligned openings to allow downward water flow, and a fourth bottom layer featuring a side outlet for filtered water discharge.

Engineering Design



Testing the Prototype

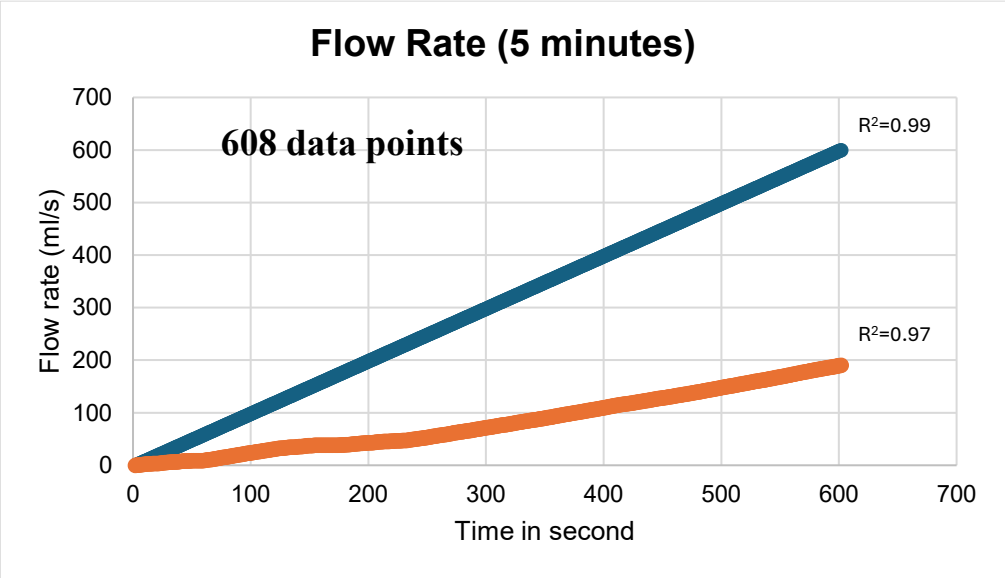
To test the flow rate, I used a Neulog drop counter sensor. I ran the flow rate experiment for five minutes

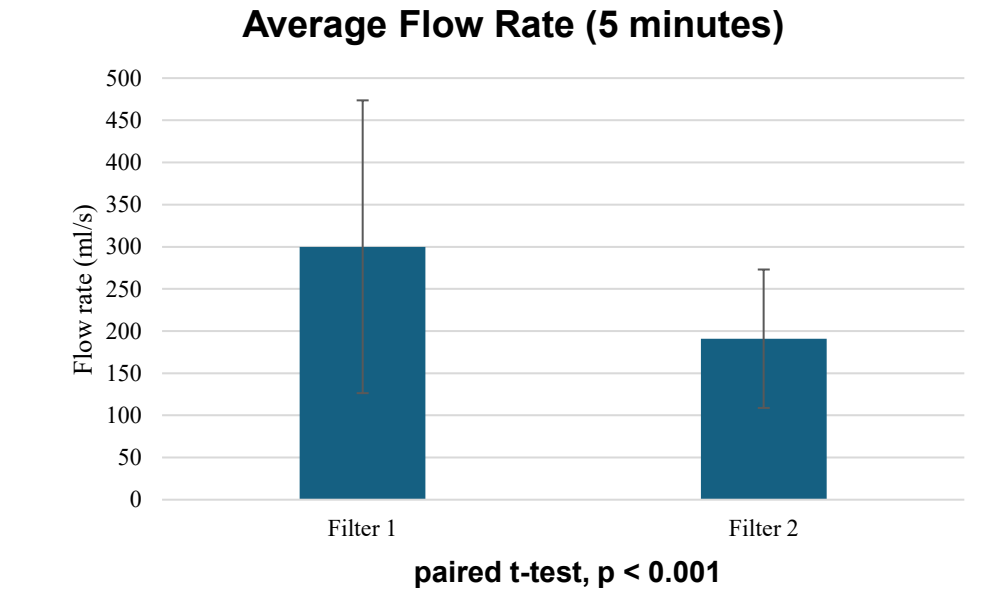


I tested the methylene blue removal capacity of the filter by creating a serial dilution. I measured the absorbance of the liquid before and after passing through the filter using a UV-vis spectrophotometer

All photos and diagram were taken/made by the student

Results: Flow Rate Analysis





Graph was created by the student using MS Excel

The cumulative flow curves increase linearly with time, indicating stable and consistent gravity-driven flow in both filters, with Filter 1 exhibiting a steeper slope that reflects a higher flow rate.

The average flow rate over five minutes was significantly higher for Filter 1 than for Filter 2, demonstrating that the filter configuration influences water output.

A paired t-test confirmed that the difference in flow rates between Filter 1 and Filter 2 was statistically significant ($p < 0.001$), indicating that the observed differences were not due to random variation.

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

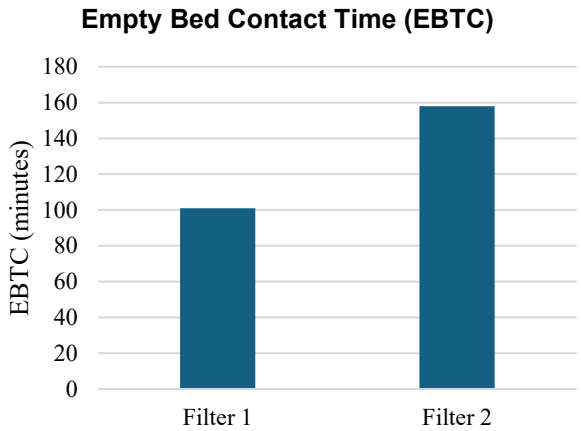
Q= V/t
V= volume collected
t= time

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

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

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

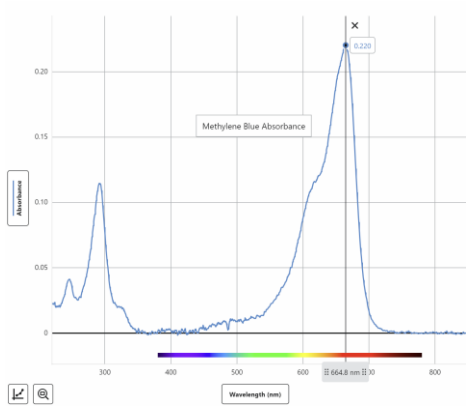
$$EBCT_2 = \frac{6060}{0.635} \approx 9543\ \text{s} = \boxed{159\ \text{min}}$$

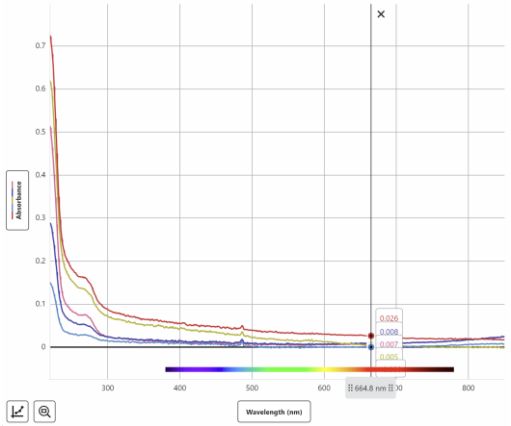


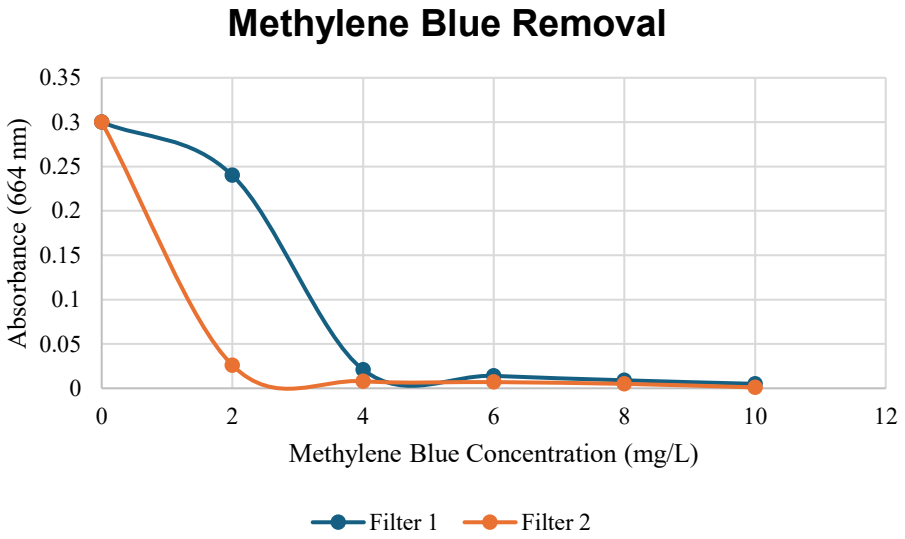
Filter 2 exhibited a higher empty bed contact time due to its lower flow rate, indicating that water remained in contact with the filtration media for a longer period. Increased EBCT is expected to enhance methylene blue adsorption efficiency.

Graph was created by the student using MS Excel; Diagram was generated using OpenAI

Methylene Blue Removal (Absorbance vs Concentration)





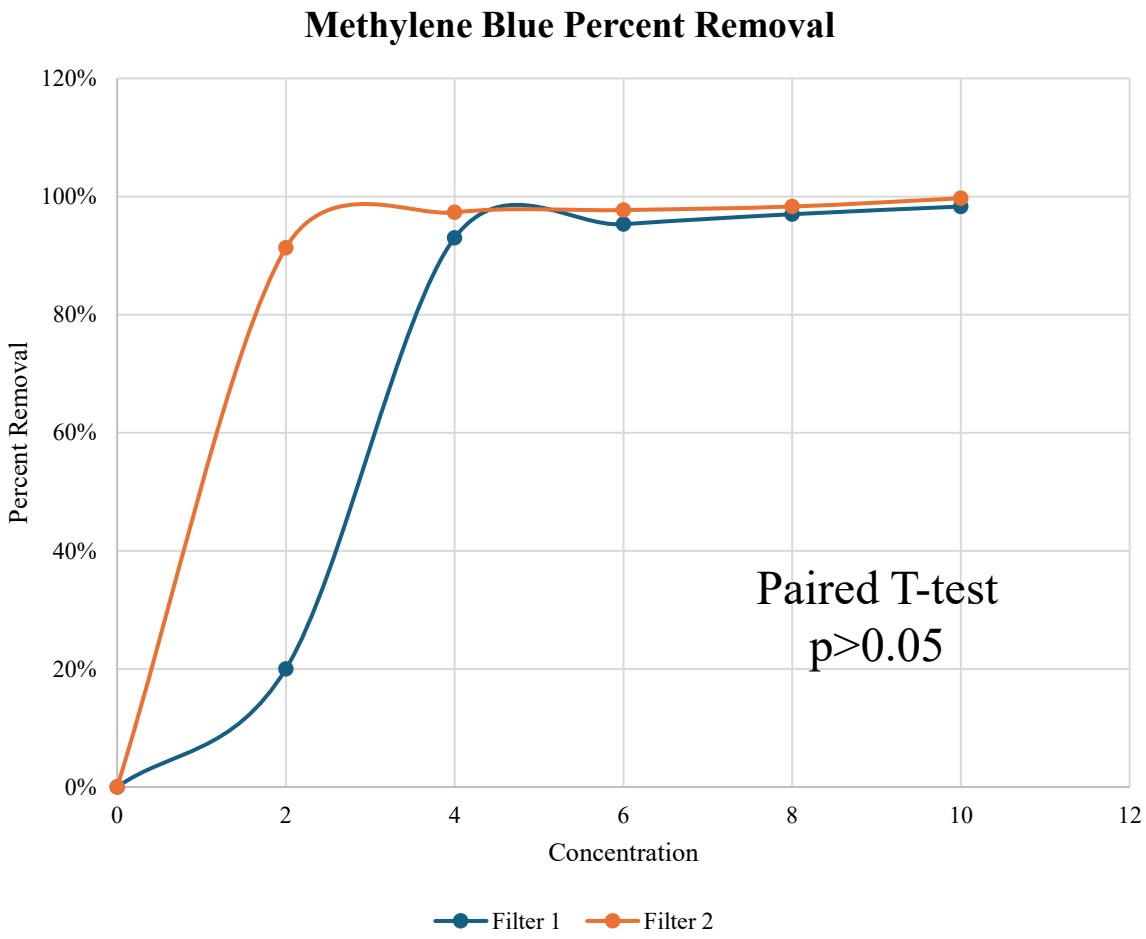


Absorbance at 664 nm decreases as methylene blue concentration increases, indicating effective removal of the dye as concentration rises, consistent with successful adsorption or degradation.

Both filters show near-complete methylene blue removal by 4 mg/L, as absorbance approaches zero, suggesting that the treatment reaches a saturation point where most dye molecules have been removed from solution.

Graph was created by the student using MS Excel; Spectral Images was generated using Vernier Spectral Analysis App

Methylene Blue Removal (Percent Removal vs Concentration)



Percent removal of methylene blue increased as concentration increased, reaching near-complete removal (95–100%) at higher concentrations, indicating strong treatment efficiency.

Both filters performed similarly across all concentrations, with no significant difference in percent removal (paired t-test, $p > 0.05$).

Graph was created by the student using MS Excel

Discussion, Conclusion, and Future Directions

Discussion

1. Does the engineered 3D-printed filtration system remove methylene blue from the water?

Yes. UV-Vis results showed a strong decrease in absorbance at 664 nm, and percent removal reached 95–100% at concentrations ≥4 mg/L, confirming effective methylene blue removal by the filtration system.

2. Does the EBCT rate affect the rate of methylene blue removal?

Yes. Filter 2 had a lower flow rate and a higher EBCT (~159 min) than Filter 1 (~50.5 min), increasing contact time with the filter media. While EBCT differed significantly ($p < 0.001$), both filters achieved similar final removal efficiencies.

3. How does the initial methylene blue concentration affect percent removal efficiency?

Percent removal increased with higher initial methylene blue concentrations, reaching near-complete removal at ≥4 mg/L. No significant difference in percent removal was observed between filters (paired t-test, $p > 0.05$).

Conclusion

The engineered 3D-printed filtration system effectively removed methylene blue from water, with higher contact time and higher initial concentrations leading to near-complete removal efficiency.

Significance

This study demonstrates that a low-cost, 3D-printed filtration system can efficiently remove dye contaminants from water, highlighting its potential for scalable, customizable, and accessible water treatment applications.

Future Directions

Future work will investigate long-term filter performance, breakthrough capacity, and regeneration of the filter media, as well as test the system using real wastewater contaminants and varying flow conditions to evaluate scalability and real-world application.

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