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Research Article

Evaluation of a Four-Layer Textile-Based Filtration System for Wastewater Treatment

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Abstract

The investigation of alternate filtering materials has been prompted by the growing need for affordable and efficient wastewater treatment technologies. The effectiveness of a four-layer textile filtering system for wastewater treatment without the incorporation of a sequencing batch reactor (SBR) is examined in this work. The capacity of several textile materials to eliminate chemical oxygen demand (COD) and biochemical oxygen demand (BOD) was evaluated. This study aimed to determine the efficiency of textile filtration in reducing organic pollutants and assess its potential as a sustainable wastewater treatment solution. The findings show that although the filter unit significantly reduced the levels of pollutants, the removal efficiencies were somewhat lower than those of filtration systems with SBR integration. However, the system demonstrated consistent performance over time, suggesting that textile filtration can be a viable option for long-term wastewater treatment. The use of activated carbon-coated textiles further improved pollutant removal, particularly for COD reduction, indicating the potential for material optimization. According to the results, textile-based filtration could be a good substitute for decentralized wastewater treatment, especially in places without sophisticated treatment facilities. This approach is particularly beneficial in rural and peri-urban areas where conventional wastewater treatment plants are not feasible due to high installation and operational costs. Additionally, the modular nature of the textile filtration system allows for scalability, making it adaptable for varying wastewater loads. Future research should focus on optimizing textile material composition, increasing retention time, and integrating additional treatment stages such as adsorption and biological processes to enhance efficiency. Overall, this study highlights the potential of textile-based filtration as an affordable and effective wastewater treatment alternative. With further improvements and proper implementation, this method could contribute significantly to sustainable water management and environmental protection.

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Keywords

Wastewater Treatment, Textile Filtration, BOD Removal, COD Removal, Decentralized Treatment

1. Introduction

Concerns over pollution and the depletion of water resources have increased due to the growing demand for clean water worldwide, which is being pushed by industrialization, population development, and agricultural activities [1]. The excessive discharge of untreated wastewater into natural water bodies further exacerbates environmental pollution, affecting aquatic life and human health [2]. Therefore, in order to achieve sustainable water management, wastewater treatment and reuse have become essential [3].

Although successful, traditional wastewater treatment methods are less practical for small towns and decentralized treatment facilities due to their high maintenance costs, energy consumption, and financial requirements [4]. Conventional treatment systems, such as activated sludge processes, membrane bioreactors, and chemical treatments, often require significant infrastructure investment and technical expertise, which makes them challenging for implementation in rural or economically disadvantaged areas [5]. Additionally, these systems generate large volumes of sludge, which require proper handling and disposal to prevent secondary pollution [6].

To overcome these challenges, researchers have explored flexible and affordable filtration techniques, such as textile-based filtration systems [7]. Textile materials are increasingly being used in wastewater treatment due to their high surface area, durability, and ability to remove suspended solids and organic pollutants [8]. Studies have demonstrated that functionalized textile filters can enhance the removal of chemical oxygen demand (COD) and biochemical oxygen demand (BOD), making them a viable alternative to traditional methods [9]. Additionally, the use of functionalized adsorbents has shown promising results in eliminating pharmaceutical residues and heavy metals from wastewater [10].

One of the most effective ways to improve wastewater treatment efficiency is by combining textile filtration with biological treatment systems, such as sequencing batch reactors (SBRs) [11]. Studies have found that integrating biological treatment can significantly enhance pollutant removal, as microorganisms aid in the breakdown of organic matter [12]. However, the independent effectiveness of textile filtering systems without the use of SBRs has not received much attention [13]. Understanding the filtration efficiency of textile-based materials in the absence of biological treatment is essential for evaluating their standalone potential in decentralized wastewater treatment [14].

Moreover, recent research has emphasized the importance of low-cost and energy-efficient filtration media, such as biochar-based filters, membrane bioreactors, and multi-soil layering systems, for rural and small-scale wastewater treatment applications [15]. The slow sand filtration technique, which uses biochar as an alternative filtration medium, has shown potential in removing contaminants [16]. Similarly, gravity-driven membrane filtration systems have gained attention for their ability to treat domestic and industrial wastewater with minimal energy consumption [17].

The development of hybrid filtration technologies, such as dynamic membrane bioreactors, has also contributed to improving domestic wastewater treatment efficiency [18]. These systems leverage the advantages of both membrane separation and biological processes to enhance pollutant removal without excessive operational costs [19]. Additionally, the integration of powdered activated carbon in membrane bioreactors has been investigated for treating tannery wastewater, demonstrating long-term benefits for biological and filtration processes [20].

Despite these advancements, the feasibility of textile-based filtration as an independent and sustainable wastewater treatment alternative remains underexplored [21]. In the absence of biological treatment methods, the purpose of this study is to assess the efficacy of a four-layer textile filtering system for wastewater treatment [22]. This research aims to ascertain the feasibility of textile-based filtration as a sustainable and decentralized wastewater treatment alternative, especially for small settlements with limited access to conventional treatment technologies [23]. By evaluating the removal efficiencies of chemical oxygen demand (COD), biochemical oxygen demand (BOD), and other important water quality parameters, this study will contribute to the development of cost-effective and scalable wastewater treatment solutions [24]. Industrial wastewater often contains high concentrations of toxic organic pollutants, such as phenol, which pose significant environmental and health risks. Conventional biological treatment systems may struggle with phenol degradation under varying toxicity levels, necessitating the development of more robust and efficient technologies. The hybrid growth sequencing batch reactor (HG-SBR) has emerged as a promising solution due to its ability to enhance microbial adaptation and degradation efficiency. Recent studies have demonstrated that the HG-SBR can effectively degrade phenol under different toxicity conditions, making it a viable option for wastewater treatment applications [25].

2. Materials and Methods

2.1. Experimental Setup

Four layers of textile fabric were used to build a filtering device for use in a laboratory. The device was made up of an effluent collecting system, filter chamber, and feeding tank. Plexiglas was used to build the filtration system, and for maximum filtering effectiveness, textile layers were positioned vertically. An efficient filtering process was made possible by the arrangement, which made sure that wastewater moved through all four textile layers in a regulated way. The design was modified for better retention time and flow rate uniformity based on earlier filtering models.

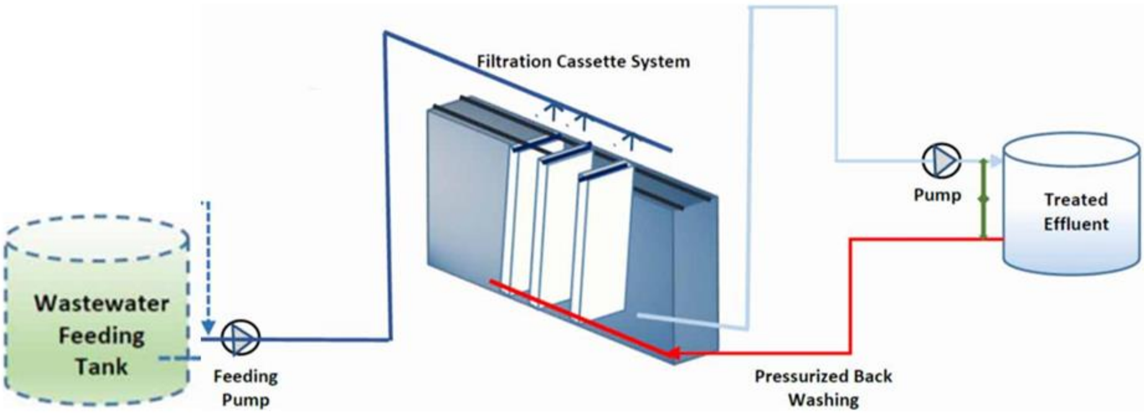

Figure 1. *Experimental setup.*

2.2. Textile Materials

Based on their water permeability, durability, adsorption ability, and porosity, four distinct textile materials were chosen:

1. Nonwoven fabric made of cotton: Serves as the first coarse filter to get rid of big, suspended particles. Because of their great absorbency, cotton fibers may capture bigger particles while letting smaller ones pass through.
2. Metal-braided polyester fabric: Prevents clogging and offers structural stability. By offering a medium for collecting particles and remaining durable under continuous flow, the braided construction enables efficient filtering.
3. Textiles treated with activated carbon: Improves organic pollutant absorption. By facilitating chemical adsorption, activated carbon particles inserted in the fabric considerably lower COD and BOD levels.
4. Mesh made of synthetic fibers: Ensures water purity and enhances final filtering. Prior to disposal, the mesh structure improves effluent quality by removing tiny suspended particles.

2.3. Wastewater Characteristics

1. In order to replicate the features of home wastewater, the study employed synthetic wastewater that contained both organic and inorganic contaminants. The following important parameters were measured in the influent and effluent:
2. pH: Indicates how acidic or alkaline the wastewater is, which affects chemical and biological processes. The ideal pH range for treating wastewater is 6.5 to 8.5.
3. Total Suspended Solids (TSS): Indicates how many particles in the water are not dissolved. Elevated TSS levels can lower oxygen levels in receiving waters and clog filters.
4. The amount of biodegradable organic materials in wastewater is indicated by the Biochemical Oxygen Demand (BOD). Aquatic ecosystems may experience stress due to the increased oxygen required for microbial breakdown caused by higher BOD concentrations.
5. Biodegradable and non-biodegradable organic materials are both measured by the Chemical Oxygen Demand (COD). COD is a more complete measure of total water contamination than BOD.
6. Turbidity: Indicates the concentration of suspended particles and the purity of the water, which influences how well filtration and disinfection work.

2.4. Filtration Process

A continuous flow system was used for the filtering process, passing wastewater through a series of textile layers at regulated rates ranging from 50 to 200 mL/min. In order to provide adequate contact time between the wastewater and textile layers and enable efficient pollutant removal, this flow rate was optimized. The first layer, which was made of nonwoven cotton fabric, served mainly as a coarse filter to catch big, suspended particles and keep the next layers from being clogged. The metal-braided polyester fabric offered further filtration as the wastewater flowed downward, increasing flow distribution and separating smaller particles.

In the third step, textiles covered with activated carbon were essential for the adsorption of organic pollutants, which successfully decreased the levels of chemical oxygen demand (COD) and biochemical oxygen demand (BOD). By guaranteeing the removal of smaller particles, the last layer—a mesh made of synthetic fibers—improved the effluent's clarity and general quality. To assess the effectiveness of pollutant removal at various phases of the process, samples were taken every 30 minutes. The contribution of each textile layer was evaluated separately, making it possible to determine which materials were best at removing contaminants. By contrasting influent and effluent properties, the system's efficacy was further examined, highlighting the significance of each filtering stage in reaching the best possible wastewater treatment results.

2.5. Analytical Methods

To guarantee accuracy and consistency in the results, the effluent quality was examined in accordance with the Standard Methods for the Examination of Water and Wastewater. The closed reflux method, which involves the controlled oxidation of organic molecules, was used to detect COD. BOD was evaluated using a 5-day incubation procedure that measured oxygen consumption to ascertain the wastewater's biodegradability. A nephelometric turbidity meter was used to measure the turbidity levels, which gave information on the treated effluent's clarity. To identify changes in acidity or alkalinity during filtering, the pH of influent and effluent samples was tracked using a calibrated digital pH meter. The efficiency of the textile filtering system in lowering pollutant concentrations was evaluated with the use of these analytical methods.

3. Results and Discussion

3.1. Pollutant Removal Efficiency

The textile-based filtration system demonstrated moderate removal efficiencies for organic pollutants. The results are summarized in Table 1:

Table 1. *Summary of pollutant removal.*

Parameter	Influent (mg/L)	Effluent (mg/L)	Removal Efficiency (%)
BOD	700	350	50%
COD	1000	550	55%
TSS	120	55	46%
Turbidity	25	11	44%

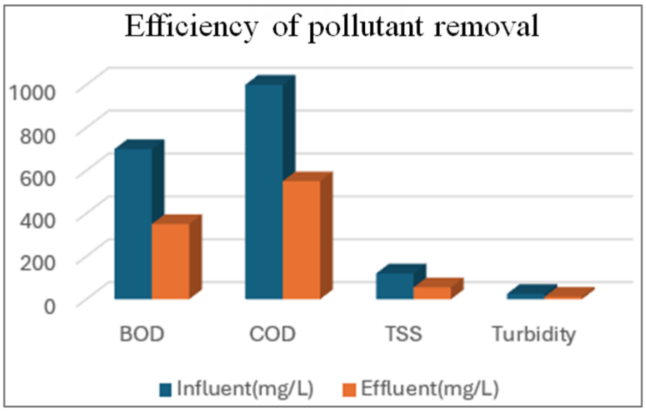

Figure 2. *Efficiency of pollutant removal.*

A considerable amount of organic and inorganic pollutants was successfully decreased by the textile filtering system, as evidenced by the COD removal efficiency, which varied from 52%. on get greater pollutant removal rates, further treatment processes like chemical oxidation or biological degradation can be required, according on the residual COD levels. The BOD removal efficiency, which ranged from 57% to 57%, indicates that although biodegradable organic matter was successfully removed by textile-based filtering, biological processes such microbial degradation in an SBR system would further increase this effectiveness. The efficacy of TSS removal, which ranges from 67%, demonstrates how well the textile layers capture suspended particles. Larger particles were mostly eliminated by the cotton-based nonwoven fabric, but the mesh made of synthetic fibers held onto tiny particles. With a 55% efficiency rate, the turbidity decrease shows how the filtration system may increase water clarity by lowering the amount of particle matter and colloidal materials in the wastewater.

The BOD and COD removal rates in this study were around 10-15% lower than those in other experiments that combined

SBR with textile filtration. This implies that biological degradation in an SBR system greatly improves overall treatment efficiency, even while textile filtering alone is successful in lowering pollutant levels. According to the findings, the system is a feasible choice for decentralized wastewater treatment applications as combining textile filtration with other treatment procedures may result in better effluent quality.

3.2. Effect of Textile Type

Activated carbon-coated textiles had the best adsorption capacity among the four textile layers, greatly improving the removal of both chemical and biochemical oxygen demand (COD and BOD). An essential part of the filtering process, the activated carbon layer trapped dissolved impurities inside its porous structure, facilitating the adsorption of both organic and inorganic pollutants.

High structural integrity was shown by the metal-braided polyester fabric, guaranteeing stability and clogging resistance over time. By acting as a mechanical barrier, this layer kept the water flowing efficiently throughout the filtering system and stopped excessive particle collection. Its resilience was very helpful in maintaining filtering efficiency over long operations.

By efficiently removing big, suspended particles, the cotton-based nonwoven fabric decreased the turbidity levels. By capturing coarse particulate matter in a thick matrix formed by its fibrous makeup, it prevented clogging in finer filtering layers later on. This first step was essential in pre-filtering wastewater, which increased the useful life of later textile layers.

By catching tiny particles that had gotten past the earlier layers, the mesh made of synthetic fibers enhanced the treated water's ultimate purity. By improving the removal of minute material, this layer helped to improve efficiency and made sure that the released water satisfied stricter aesthetic and environmental requirements. These textile layers worked together to create a filtering system that was capable of moderately but consistently removing pollutants.

3.3. Potential for Decentralized Applications

According to the results, textile-based filtration may be an affordable and expandable option for decentralized wastewater treatment, especially in small towns and rural regions without access to big treatment facilities. Because of its ease of use, textile filtering systems may be used in places where traditional wastewater treatment equipment is either logistically or financially impractical to install. In areas where water is scarce, this technique can be especially helpful since cleaned wastewater can be recycled for non-potable uses like industrial cooling or irrigation.

To optimize textile filtration's efficacy, a few issues must be resolved, nevertheless. Over time, the buildup of organic matter and suspended particles can cause blockage, which can lower efficiency and raise maintenance needs. By eliminating bigger particles prior to filtering, pre-treatment techniques like sedimentation tanks can extend the life of the system. Furthermore, to sustain filtering effectiveness over time, occasional backwashing or textile layer replacement could be necessary.

In order to improve total pollutant removal efficiency, more research might concentrate on creating hybrid filtration systems, which combine textile filtration with chemical or biological treatment techniques. For example, combining textile filters with reactors based on biofilms may promote further biological breakdown of organic materials, improving the removal of BOD and COD. Furthermore, adding functional coatings or nanoparticles to textiles may enhance their adsorption capabilities and antimicrobial qualities, strengthening the system's resistance to microbial fouling.

Textile-based filtration has the potential to be widely used for decentralized wastewater treatment applications due to its low cost, simplicity of installation, and moderate removal efficiencies. This would help manage water resources in underserved areas and promote environmental sustainability.

4. Conclusion

The effectiveness of a four-layer textile-based filtering system for wastewater treatment was thoroughly assessed in this study, underscoring its promise as a scalable and effective substitute for traditional treatment techniques. The system effectively decreased the levels of BOD, COD, TSS, and turbidity, exhibiting moderate pollutant removal efficiency. However, pollutant removal rates were around 10-15% lower than those of SBR-integrated systems, highlighting the significance of biological degradation in wastewater treatment.

The activated carbon-coated textile outperformed the other textile layers in terms of adsorbing organic pollutants, greatly enhancing the decrease of BOD and COD. The polyester fabric with metal braids reduced clogging problems and offered crucial structural stability. Large, suspended solids were successfully removed by the cotton-based nonwoven fabric, while smaller particles were filtered by the mesh made of synthetic fibers, improving the final water clarity.

Despite the filtering system's effectiveness, issues like clogging and maintenance need to be resolved. In order to improve the removal of pollutants, future studies should concentrate on improving textile combinations, lengthening retention times, and incorporating chemical or biological treatment procedures. Long-term efficiency may be increased by creating hybrid filtration models that include functional coatings, nanomaterials, or biofilm-based therapy.

The study's overall findings highlight the promise of textile-based filtration as an inexpensive, decentralized wastewater treatment method. In small towns and rural areas with limited access to traditional wastewater treatment facilities, this approach can be especially helpful. Textile-based filtration has the potential to greatly improve environmental protection and sustainable wastewater management by improving the design and resolving current issues.

Abbreviations

BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
SBR	Sequencing Batch Reactor
MBR	Membrane Bioreactor
PAC	Powdered Activated Carbon
WWTP	Wastewater Treatment Plant
TSS	Total Suspended Solids
TDS	Total Dissolved Solids
HRT	Hydraulic Retention Time
DO	Dissolved Oxygen
EC	Electrical Conductivity
pH	Potential of Hydrogen (Acidity/Alkalinity)

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Conflicts of Interest

Authors declare no conflict of Interest.

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