DUAL FILTRATION SYSTEM: INTEGRATION OF PHYSICAL–CHEMICAL AND FUNGAL-BASED BIOLOGICAL FILTERS FOR TEXTILE AND BATIK WASTEWATER TREATMENT

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Abstract. Textile and batik wastewater containing synthetic dyes such as brown Naphtol red, green Indigosol, and blue Procion poses serious environmental challenges due to its toxicity and persistence in aquatic ecosystems. Conventional treatment using a physical–chemical method has demonstrated considerable decolorization efficiency, but the effluent remained cloudy because fine particles and dissolved dye residues were not fully removed. In addition, previous studies have highlighted the promising role of fungi in dye degradation, particularly *Aspergillus sp*. 3, which has shown strong potential for decolorizing synthetic dyes. This study aimed to develop and evaluate a dual filtration system by integrating physical–chemical filtration (cotton fiber, activated carbon, zeolite, sand, gravel) with fungal-based biological treatment using *Aspergillus* sp.3 in Potato Dextrose Broth (PDB) medium. The experimental method involved treating textile wastewater containing three representative dyes—Naphtol red-brown, Indigosol green, and Procion blue—using physical–chemical filtration alone and physical–chemical filtration combined with *Aspergillus* sp. 3-based biological filtration. The decolorization percentage was measured spectrophotometrically to assess treatment performance. The results showed a significant improvement in decolorization with the dual filtration system. While physical–chemical filtration alone achieved 98.18% (Naphtol red-brown), 78.09% (Indigosol green), and 66.11% (Procion blue), the integrated system with *Aspergillus* sp.3 increased decolorization to 99.70%, 99.46%, and 97.73%, respectively. These findings demonstrate that the integration of physical–chemical and fungal-based biological filters, with *Aspergillus* sp.3 as the biodegradation agent, provides a more effective solution than physical–chemical filtration alone, producing clearer effluent with near-complete dye removal. This dual system has strong potential as a sustainable technology for treating wastewater from the textile and batik industries.
Keywords: *Aspergillus* sp.3, batik effluent, dual filtration system, fungal biodegradation, textile wastewater.

1. Introduction

The batik and textile industry is an important sector in the Indonesian economy, but it produces liquid waste with complex characteristics, dark colors, and poor biodegradability. The main contents of this waste include synthetic dyes, aromatic compounds, surfactants, and free fatty acids from the cleaning and bleaching processes. Synthetic dyes such as Naphtol, Indigosol, and Procion have complex aromatic structures that make them persistent in the environment and potentially toxic to aquatic organisms if not properly handled [1]. The presence of dyes in wastewater reduces light penetration, inhibits photosynthesis, increases biological load, and can produce toxic by-products during natural degradation.

Various physical-chemical technologies have been used for textile wastewater treatment, including coagulation-flocculation, membrane filtration, and activated carbon adsorption. Although these methods can reduce color, fine-particle residues and dissolved compounds often persist, causing the effluent to remain turbid and fail to meet certain quality standards [2]. Therefore, alternative technologies that are more effective, sustainable, and capable of optimally removing color are needed.

In recent years, fungi (particularly white-rot fungi) have become an important topic in textile waste bioremediation due to their ability to produce extracellular enzymes such as laccase, lignin peroxidase, and manganese peroxidase, which can degrade complex aromatic structures in synthetic dyes [3], [4]. Rajhans et al. (2021) reported that fungi can remove color through biosorption and enzymatic biodegradation, which are highly effective against azo and anthraquinone dyes [1]. In addition, the integration of physical-chemical filtration systems with fungus-based biological filtration has been shown to improve effluent clarity and treatment process stability. Recent studies show that combining physical adsorbents (activated carbon, zeolite, cotton fiber, sand) with fungi achieves nearly 100% decolorization of several synthetic dyes [4], [5].

Although physical-chemical filtration methods have reduced the color intensity of wastewater to a fairly high level, this approach still has limitations. The effluent is generally still cloudy due to the presence of fine particles, dissolved dye residues, and organic compounds that are not completely filtered [1,2]. This condition indicates that physical filtration alone is insufficient to produce effluent that is completely clear and safe for discharge into the environment.

On the other hand, previous studies have highlighted the potential of fungi, particularly Aspergillus sp.3, as effective biodegradation agents for degrading synthetic dyes through biosorption and enzymatic activity, thereby achieving higher decolorization levels than physical-chemical methods alone [1,3]. These findings present a valuable opportunity to develop a more comprehensive wastewater treatment system by integrating two distinct approaches.

Based on these requirements, this study focuses on the development of a dual filtration system that combines physical-chemical filtration as a pre-treatment stage with biological filtration using *Aspergillus* sp.3 in liquid medium. The integration of these two systems is expected to overcome the shortcomings of single methods, produce clearer effluent, improve the decolorization efficiency of three main types of dyes (brown naphthol red, green indigosol, and blue procion), and provide a sustainable solution for textile and batik waste treatment.

2. Methods

2.1. Location and Sample Sources

This study used liquid waste collected from wastewater treatment facilities at textile/batik production units that routinely use Naphtol brown red, Indigosol green, and Procion blue dyes. Samples were collected at the outlet of the dyeing process after cooling, stored in dark containers at 4°C, and analyzed within 48 hours to prevent chemical composition changes from natural degradation. The selection of these three dyes was intended to represent the classes of dyes commonly used in the batik and textile industries and to have different environmental resistance characteristics, so that the evaluation of the double filtration system could be carried out in a representative manner [1].

2.2. Physical–Chemical Filtration Materials and Devices

The materials used for the physical–chemical filtration unit included cotton fibers, activated carbon, zeolite, fine sand, and gravel. These materials were prepared, washed, and conditioned in accordance with standard laboratory procedures to remove loose particles or contaminants that might affect absorbance measurements. The combination of granular materials and adsorbents was selected based on the principle of layered action to capture suspended particles and adsorb dissolved dye molecules, thereby improving effluent clarity prior to biological treatment [2]. The filtration columns were arranged in the same configuration for each treatment replicate to ensure hydraulic consistency and contact time.

2.3. Preparation and Inoculum of *Aspergillus* sp.3

Aspergillus sp. 3 isolates were revived on Potato Dextrose Agar (PDA) medium to obtain active colonies, and spores were harvested with a sterile NaCl solution and concentrated to a standardized density. The spore suspension was inoculated into Potato Dextrose Broth (PDB) and incubated at 28–30°C with shaking at 150 rpm for 48 hours to produce an active liquid culture. This step follows the inoculum preparation protocol commonly used in fungal bioremediation studies, as inoculum density and growth phase affect enzymatic activity and biosorption capacity during biological treatment [1,3].

2.4. Experimental Design and Treatment

The experimental design consisted of two main treatments. First, single physical–chemical filtration in which the waste was passed through a layered column (cotton fiber → activated carbon → zeolite → sand → gravel) with gravity-controlled flow; the filtrate from this treatment was collected for measurement. Second, a double filtration system in which the filtrate from physical-chemical filtration is fed into a liquid culture reactor containing *Aspergillus* sp.3 in PDB for further biological treatment. Both treatments were carried out in triplicate for each dye type to obtain representative data and apply basic statistics when comparing efficiency [2]. This design allows evaluation of the relative contributions of physical-chemical filtration and the added value provided by *Aspergillus* sp.3-based biological filtration.

2.5. Biological Filtration Operating Conditions

Biological treatment was carried out on liquid cultures containing *Aspergillus* sp.3 at 28–30°C with agitation at 150 rpm to maintain suspension uniformity and contact between the biomass and dye molecules. The biological contact time was set at 48 hours, based on the literature indicating the optimal range of enzymatic degradation activity in filamentous fungi toward synthetic dyes [1,4]. During incubation, parameters such as pH, temperature, and dissolved oxygen were recorded to ensure consistent conditions between replicates. The roles of biosorption and enzymatic activity were assumed to work simultaneously; therefore, the biological treatment was designed to allow sufficient time for these mechanisms to contribute to the decrease in absorbance.

2.6. Decolorization and Quality Parameter Measurements

Decolorization was measured using a UV-Vis spectrophotometer at the characteristic maximum wavelength of each dye; initial absorbance (A_0) and absorbance after treatment (A_t) were recorded. The percentage of decolorization was calculated using the standard formula:

$((A_0 - A_t)/A_0) \times 100$. Furthermore, additional parameters such as turbidity (NTU), pH, and Total Organic Carbon (TOC) were measured to assess effluent clarity and organic load recovery, as visual clarity does not always reflect the total reduction of dissolved contaminants [2,5]. Measurements were performed for each replicate sample at the same time after treatment.

3. Results And Discussion

3.1. Effectiveness of Physical-Chemical Filtration

Physical-chemical filtration can reduce the color intensity of the three types of synthetic dyes tested. The decolorization percentages were 98.18% for brown naphthol red, 78.09% for green indigosol, and 66.11% for blue procion. These results indicate that the layered filtration mechanism using cotton, activated carbon, zeolite, sand, and gravel is quite effective in removing suspended particle fractions and some dissolved dye compounds.

The high decolorization rate of Naphtol brown red may be due to its molecular structure, which is more readily adsorbed by activated carbon, whereas the other two dyes, especially Procion blue, have more stable structures and tend to be more difficult to separate from solution. This phenomenon is in line with findings from several studies indicating that the effectiveness of adsorption is influenced by the structure of the chromophore and the electronic substituents of synthetic dyes [1].

However, despite its high efficiency for certain dyes, physical-chemical filtration still produces cloudy effluent. This indicates the limitations of this method in removing fine particles and soluble dye residues that cannot be completely captured by the granular media [2].

Table 1. Percentage of Physical–Chemical Filtration Decolorization

Dye Type	Decolorization Percentage (%)
Naphthol red brown 98.18%	98.18%
Indigosol green 78.09%	78.09%
Procion blue 66.11%	66.11%

Table 2. Comparison of the Effectiveness of Physical–Chemical Filtration and Dual Filtration Systems

Dye Type	Dual Filtration (Physical–Chemical + *Aspergillus* sp.3) (%)
Naphthol red brown	99.70%
Indigosol green	99.46%
Procion blue	97.73%

3.2. Effectiveness of the Dual Filtration System

When physical-chemical filtration is combined with biological filtration based on *Aspergillus* sp.3, there is a significant increase in decolorization. This dual system achieves 99.70% decolorization of brown naphthol red, 99.46% of green indigosol, and 97.73% of blue procion, all higher than those achieved by physical-chemical treatment alone.

This increase indicates that fungi play an important role in degrading dye molecules that are not adsorbed by physical filtration media. *Aspergillus* sp. 3 is known to produce oxidative enzymes such as laccase, manganese peroxidase, and lignin peroxidase, which break chromophore bonds and aromatic structures in synthetic dyes [1,3]. The presence of these enzymes enables fungi to degrade dye residues that are more resistant to adsorption.

These results are consistent with various studies indicating that integrating physicochemical and biological technologies yields a synergistic effect, as biological processes can continue degrading residues after physical filtration is complete [2,3,4].

When compared, physical-chemical filtration is effective as a pre-treatment because it can quickly reduce color load and decrease the initial concentration of dye molecules. However, this system cannot degrade more chemically stable molecules. In contrast, the biological process by *Aspergillus* sp.3 focuses more on the enzymatic transformation of compounds that are difficult to break down. Therefore, when the two processes are combined, physical filtration reduces the initial contaminant load, while biological filtration completes the degradation of dye residues almost completely. This explains why the double filtration system achieves near-perfect decolorization across all dye types, whereas a single physicochemical treatment reached only 66.11% for Procion blue.

The results of the study show that the dual filtration system (physical-chemical + biological, based on Aspergillus sp. 3) achieves a much higher decolorization percentage than physical-chemical filtration alone. This difference emphasizes that the biological stage by fungi can break down dye residues that are not handled by the physical-chemical stage. Recent studies show that fungi employ two main mechanisms: biosorption of dye compounds onto cell walls and enzymatic biodegradation via enzymes such as laccase, manganese peroxidase, and lignin peroxidase. [6]

In practice, the physical-chemical pre-filtration stage reduces the main dye load, making biological conditions more conducive to fungi working optimally. This combination aligns with the "multistage treatment" principle in textile waste treatment, which is increasingly recommended in the literature. [7]

From the data obtained, Naphtol brown red dye showed high decolorization in both physical-chemical filtration (98.18%) and the dual system (99.70%). This is likely due to its chemical structure, which is more easily adsorbed and accessed by fungal enzymes. In contrast, Procion blue reached only 66.11% in physical-chemical filtration, but increased dramatically to 97.73% in the dual system. These findings indicate that dyes with stable and environmentally resistant structures require a biological stage for further degradation. The literature indicates that the more complex the chromophore structure and the color-changing substituents, the greater the role of fungal enzymes in the degradation process. [8]

The success of the double filtration system in this study cannot be separated from the synergy between physical-chemical and biological mechanisms that work sequentially. In the initial stage, the layered filtration media consisting of cotton, activated carbon, zeolite, sand, and gravel removed various particulate components and some dissolved dyes. Activated carbon plays a dominant role in this process due to its highly effective adsorption of charged molecules, especially from the azo and indigosol groups, thereby significantly reducing the color load in the filtrate [2]. This reduction in initial concentration creates a more stable environment for the subsequent biological stage.

After undergoing physical-chemical filtration, the remaining dye residues then undergo further degradation by fungi. Aspergillus sp. 3 works through biosorption and the production of oxidative enzymes such as laccase, lignin peroxidase, and manganese peroxidase, which can degrade the dye's chromophore. This process results in a change in chemical structure, so the color is permanently lost rather than simply transferred to the filtration medium. Various studies have confirmed that white-rot fungi and Aspergillus species are highly efficient biodegradators of complex aromatic compounds and azo dyes, making them important agents in the bioremediation of colored waste [1,3,4].

The synergy of these two mechanisms—adsorption and filtration by layered media, and enzymatic biodegradation by fungi—explains why the dual filtration system achieves a much higher level of decolorization than either method alone. Initial filtration reduces the pollutant load, while the biological stage completes the degradation of dye residues to near completion. The end result is a much clearer, more stable effluent that shows significant improvements in both visual and analytical quality.

In the physical-chemical stage, materials such as activated carbon, zeolite, and sand perform adsorption and mechanical filtration that reduce the number of particles and some dissolved dyes. However, the final waste may still contain dissolved molecules that are not easily adsorbed. The biological stage provides the best function, enabling fungi to handle residual compounds through oxidative enzymatic activity and additional biosorption. This concept is supported by reviews noting that fungi are highly effective biocatalytic tools for colored textile waste due to their ability to produce aggressive extracellular enzymes and to adapt to operational conditions. [6][9]

4. Conclusion

The conclusions that can be drawn from this study are:

4.1. A dual filtration system combining physical-chemical filtration and biological filtration based on Aspergillus sp.3 proved to be more effective than physical-chemical methods alone.

4.2. Decolorization improvements were achieved for all types of dyes: Naphtol brown red (99.70%), Indigosol green (99.46%), and Procion blue (97.73%).

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