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Biodegradation and environmental impact of kenaf fiber water filters: Towards sustainable water purification solutions

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ABSTRACT
This study evaluates the efficacy of kenaf fiber water filters with particular emphasis on filtration efficiency, biodegradability, and structural properties. Characterization techniques such as Fourier Transform Infrared Spectroscopy (FTIR), Scanning Electron Microscopy with Energy Dispersive X-ray Spectroscopy (SEM-EDX), X-ray Diffraction (XRD), and Thermogravimetric Analysis (TGA) have been employed to analyze the fibers. The investigation compares untreated and chemically treated kenaf fibers regarding their ability to remove contaminants including turbidity, nitrate, phosphate, Total Dissolved Solids (TDS), Biochemical Oxygen Demand (BOD), and Chemical Oxygen Demand (COD). FTIR analysis indicated that chemical treatment modifies certain functional groups, enhancing water resistance of the fibers. SEM-EDX results showed that treated fibers are more porous and possess smoother surfaces, which improve their capacity to trap contaminants effectively. XRD analysis revealed a significant increase in the fibers' crystallinity index from 44.3% in untreated fibers to 76.87% in treated fibers contributing to enhanced filtration performance. TGA confirmed that treated fibers exhibit greater thermal stability, with degradation temperatures rising from 240°C to 280°C. When compared to synthetic and ceramic filters, kenaf-based filters are environmentally friendly and cost-effective. The filters demonstrated high removal efficiencies, such as 99.98% for turbidity, 96.85% for phosphate, and 92.76% for chlorine. A notable advantage of kenaf fibers is their biodegradability, as they disintegrate within 90 days, thereby reducing environmental impact over time. Despite ongoing challenges related to durability and large-scale production, these findings suggest that kenaf is a promising and sustainable option for water filtration applications.

Contribution/Originality: This study is the first to combine the filtration efficiency, biodegradability, and structural properties of kenaf fiber water filters into a single, comprehensive investigation. This distinguishes it from previous studies.

1. INTRODUCTION

Water pollution continues to be a significant challenge worldwide, threatening human health, biodiversity, and socio-economic stability. Heavy metals, pathogens, microplastics, and agricultural runoff pollute water bodies, degrading water quality and restricting accessibility. Liu, Liu, Huang, Fu, and Huang (2020) further state that nature-based solutions such as bio-slow sand filtration are rapidly gaining momentum as water purification alternatives to save energy while maintaining high efficiency in contaminant removal. The leading water filtration methods have traditionally been reverse osmosis, activated carbon adsorption, and chemical coagulation (Kausar, 2024). However, these traditional methods have certain drawbacks, including their adverse impacts on the environment, such as higher operational costs and energy consumption, along with secondary pollution (Mishra et al., 2024). The great need for sustainable water purification methods has initiated an investigation into plant-based filtration methods that satisfy the requirements of being environmentally friendly, cost-efficient, and biodegradable.

Natural fiber-based filters are other options in the group of plant materials being tested for water purification. Cotton-based carbon filters, for instance, have exhibited an enhancement in adsorption capacity due to an increase in surface area and changes in chemical composition during carbonization (Morad et al., 2023). In the same fashion, another nanocomposite membrane comprising cellulose nanocrystals demonstrated enhanced longevity and higher rejection rates of contaminants (Mishra et al., 2024). Kenaf (Hibiscus cannabinus), being a fast-growing fiber crop, has emerged as a highly attractive material due to its porosity, mechanical strength, and biodegradability. Several studies indicate that kenaf fiber exhibits high adsorption capacity for removing both organic and inorganic pollutants (Guo et al., 2020). Furthermore, its antimicrobial property prevents bacterial growth, adding more value to its standing as a green filtration medium (Sudiyani et al., 2022). This study analyzes the possibility of using kenaf fiber for water purification by examining its biodegradation rate, environmental impact, and filtration efficiency.

This study investigated kenaf fiber water filters as a sustainable alternative to conventional filter systems. It assessed the ability of kenaf fiber filters to remove turbidity, nitrate, phosphate, total dissolved solids (TDS), and organic contaminants. In addition, the environmental implications of kenaf-based filters were compared with those of other biodegradable materials, such as coconut husk and wood sawdust. This study has contributed to sustainable water purification technologies by narrowing the gap in knowledge in plant-based filtration and consequently reducing dependency on synthetics.

2. MATERIALS AND METHODS

2.1. Materials Used

The potential of kenaf fiber for water filtration applications was studied following some pre-treatments to impart better functional properties to the fibers. The kenaf fibers, obtained from the Department of Textile Technology at the National Research Institute for Chemical Technology (NARICT) in Zaria, were subjected to phosphoric acid surface modification treatments. The phosphoric acid treatment was carried out to enhance the adsorptive capacities of the fibers, as has been previously highlighted in the studies of Razak et al. (2020) and Hossain, Siddiquee and Kumar (2021). The treated fibers were then characterized to determine the effectiveness of the treatment process in terms of alterations in chemical composition, surface morphology, crystallinity, and thermal stability.

Kenaf fiber characterization involved several analyses. Infrared spectroscopy of FTIR was employed to detect important functional groups within the range 4000–400 cm−1. This supports, with very critical evidence toward the chemical transformation, especially for confirming the removal of hydroxyl (-OH) groups after alkali treatment. This particular point is very crucial because it depicts the successful modification of the fibers that led to an improvement in their hydrophobicity and thus a decreased moisture absorption, in line with the research of Bhambure, Rao, and Senthilkumar (2021). At a microscopic level and from an elemental standpoint, the SEM-EDX analysis showed another remarkable change occurring in the fiber surface. The untreated fibers had rough surfaces with visible impurities on them, while the treated fibers exhibited a clean surface that was slightly porous, which is beneficial from an adsorption standpoint (Ebrahimi, Koosha, Hamedi, Vatankhah, & Shidpour, 2024). The variation in elemental composition, as checked by EDX, pointed toward increased exposure of cellulose, which further aids the fiber's applicability in various filtration applications.

More than the chemistry of the surface, the structural and thermal characterization of the fibers has been studied in detail. However, the XRD analysis showed a substantial increase in the crystallinity index (CI) of the fiber from 44.3% in untreated fibers to 76.87% after treatment. This increase is a clear indication of the enhanced structural integrity and mechanical strength of kenaf fiber, according to Silva, Lemos, and Monteiro (2021). TGA also showed that the treated fibers had higher thermal stability. Their degradation temperature was increased from 240°C to

280°C, thereby confirming the hardening of the fibers against heat and their long life. These findings collectively provide strong confirmation of the chemical modification's efficiency in enhancing the major properties of kenaf fibers, thereby making them extremely suitable for applications in sustainable filtration and composites.

2.2. Preparation of Kenaf Fiber Water Filters

The preparation of the kenaf fibers began with a retting process that used an optimized bacteria-water solvent system with alkalophilic pectinase-producing bacteria. This process is absolutely essential for attaining good fiber cellulose purity by breaking down fiber non-cellulosic elements (Hossain, Subbiah, & Siddiquee, 2022). After retting, the fibers were treated with potassium permanganate to increase tensile strength and reduce water absorption (Judawisastra & Refiadi, 2022). To test mechanical durability, especially under the continuous flow of water, the treated kenaf fibers were then hybridized with glass fibers along with an epoxy resin (Mahmoud, 2021).

2.3. Experimental Setup

In order to assess the filter efficiency of the kenaf fiber filters in a mock-up real environment, a vertical column filtration system was custom-built for testing. This system integrates layers of kenaf fibers with polymeric supports to allow for specified flow rates. The efficiency of filtration takes into account water samples collected before and after processing.

2.4. Water Quality Parameters Measured

To evaluate the system more comprehensively, several key water quality parameters were tested, all according to standard procedures. These include physical properties such as turbidity, total dissolved solids (TDS), and color changes, so that the removal of suspended and dissolved pollutants can be quantified (Sidik, Mohamed, Baba, & Mohd, 2022). To gain insight into the degradation of the materials, the effect of water absorption on the kenaf fiber composites was also studied concerning time (Mustapha, Mustapha, Suriani, Ruzaidi, & Awang, 2021).

Besides, the chemical contaminants removal ability was analyzed through pH measurement (Abdullah, Zakaria, Anuar, Salleh, & Jaafar, 2020), chloride, nitrate, and phosphate concentration methods (Abdullah et al., 2020). Further chemical interactions between the kenaf fibers and these pollutants were studied using Fourier-transform infrared (FTIR) spectroscopy (Bhambure et al., 2021). The organic matter removal efficiency was assessed through TOC, BOD, and COD measurements (Ibrahim, Awang, & Jusoh, 2020).

2.5. Biodegradability Assessment

In measuring the biodegradability of the kenaf fiber filters, eco-friendliness was examined. The rate of degradation was tested under varied environmental conditions, including soil and aquatic exposure (Austin, Mondell, Clark, & Wilkie, 2024). Microbial degradation was then measured to completely assess the breakdown of the filter (Hossain, Siddiquee, et al., 2021), and the effect of such biodegradation on the quality of the soil and water was analyzed by elemental composition (Pachappareddy, Padhy, & Pendyala, 2024).

3. RESULTS AND DISCUSSION

3.1. FTIR Analysis

Fourier-transform infrared (FTIR) spectroscopy is highly useful for identifying functional groups or analyzing chemical modifications in materials. Differences observed in the FTIR spectra of untreated and chemically treated kenaf fiber reveal significant changes during the treatment. The spectroscopic shifts, along with the appearance or disappearance of specific absorption bands, clearly establish whether chemical modification has occurred.

The initial analysis aimed to consider the hydroxyl and aliphatic regions of the spectra. Both untreated and treated fibers show a broad absorption band in the O–H stretching region (3700–3000 cm−1) due to cellulose's numerous hydroxyl groups. Some peaks in this zone are significantly diminished or even eliminated in the treated fibers, with the obvious implication that free hydroxyl groups have been greatly reduced. This observation is consistent with chemical treatments that either replace or cap these groups, making the fiber less hydrophilic. Similar downshifts are observed in the C–H stretching region (3000–2800 cm−1), indicating modifications on the aliphatic C–H2 groups, probably due to esterification or etherification reactions.

Chemical changes are observed in other major parts of the spectrum. Similarly, in the carbonyl stretch area ranging from 1750–1650 cm−1, the disappearance of a distinct peak at a wavenumber of 1751.42 cm−1 for the treated fiber, compared to a shift to 1597.11 cm−1 on the treatment points, indicates an alteration in the carbonyl groups, possibly through the formation of new functional groups or esterification of existing ones. Shifts across the aromatic ring stretch and C–H bend (1600–1450 cm−1) may suggest lignin removal or other structural changes within the fiber matrix. Furthermore, a shift in the C≡C and C≡N stretch (2300–2200 cm−1) from 2355.16 cm−1 to 2297.3 cm−1 could represent nitrile group installations or conjugated alkyne structures during treatment.

The spectral data of treated fibers attest to the formation of entirely new functional groups. In the area typical of C–O and C–H deformation (1300–1000 cm−1), additional peaks at 1319.35 and 1267.27 cm−1 emerge as characteristic of successful esterification or etherification reactions. In the fingerprint region (900–600 cm−1), mostly void of features of such nature on the untreated fibers, new peaks at 783.13 and 709.83 cm−1 have now become evident. The introduction of these peaks denotes expansive structural modifications, possibly linked to the presence of substituted aromatic rings. To conclude, the entire series of changes evidenced in the FTIR spectrum, from the decrease in hydroxyl groups to the appearance of new peaks, are serious probes supporting the view that the chemical treatment actually affected the chemical structure of the kenaf fibers, thus reducing their hydrophilicity and incorporating them with new functional groups. The spectra of the untreated and treated kenaf fibers are given in Figure 1.

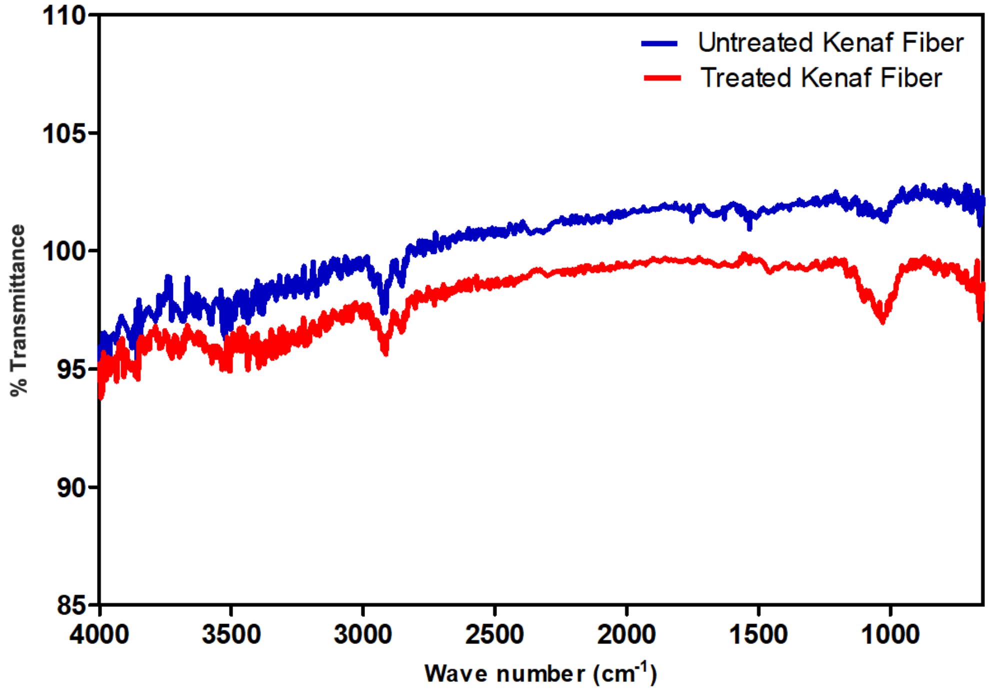

Figure 1. FTIR spectra of untreated and treated kenaf fiber.

3.2. XRD Analysis

The XRD characterization of Kenaf fiber provides a clearer understanding of its structural and crystalline properties before and after chemical treatment. It was found that the XRD pattern indicated a significant increase in the Crystallinity Index; i.e., from 44.3 percent in untreated fibers to 76.87 percent in treated fibers. This substantial increase suggests that the chemical treatment has promoted the development of an ordered and compact structure, which can enhance mechanical strength and durability for applications such as filtration.

This increase in crystallinity is directly attributable to the removal of the non-cellulosic constituents of the fiber, such as lignin and hemicellulose. Such substances normally constitute physical shields that prevent the tight packing of cellulose chains. By removing them, the treatment relieves the cellulose to re-align into a more crystalline structure. Such structural improvement is of prime importance since it mainly confers resistance to mechanical stresses and enhances performance in the water filtration process, primarily for processes demanding strength and longevity. Besides, the said structural alterations indicate that the treated kenaf fibers would be more resistant to biodegradation, thus propelling them as targets for sustainable and long-lifespan filtration systems.

The results are consistent with findings from similar treatments in other studies. For instance, Narkpiban and Poonsawat (2020) showed that the hydrothermal pretreatment had largely positively affected the crystallinity of kenaf fibers. Also, Ebrahimi et al. (2024) observed a major increase in the crystallinity of modified kenaf fibers, thereby demonstrating that chemical modifications are an effective method for enhancing mechanical properties and compatibility with other materials. Figure 2 illustrates the XRD pattern of untreated and treated kenaf fibers for water filtration.

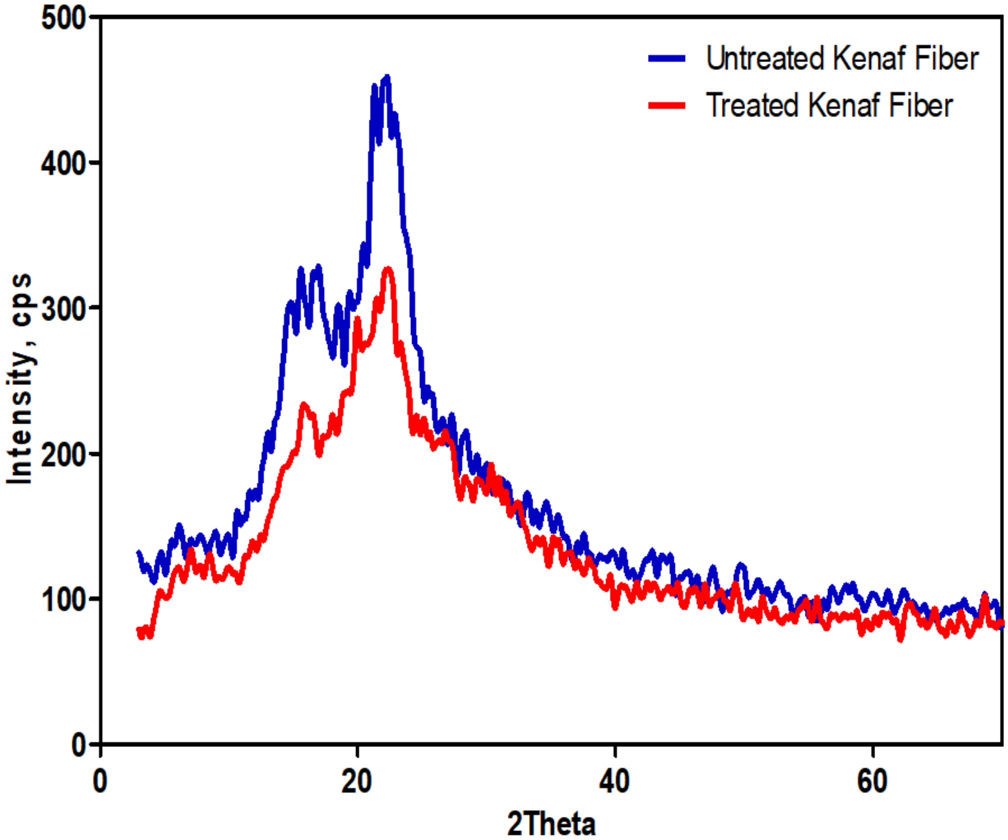

Figure 2. XRD pattern of untreated and treated kenaf fiber.

3.3. SEM – EDX Analysis

3.3.1. SEM Analysis

SEM was deployed in viewing and comparing the surface morphology of the untreated and treated kenaf fibers. From the SEM images shown above, it is evident that the untreated fibers had their surfaces rough and irregular, with impurities evident, while the fibrous structures appeared entangled and loosely bound. This morphology indicated the presence of certain non-cellulosic materials such as lignin and hemicellulose that block the separate cellulose fibers from developing an even surface. This type of undesirable surface might affect the mechanical properties of the fiber adversely and hinder the development of interfacial bonding in composites.

In contrast, a remarkably cleaner and smoother surface characterizes treated kenaf fibers. Such chemical treatment removes surface impurities effectively and separates the individual fibers with a more uniform structure. With higher purity and smoothness, fiber qualities are enhanced because of greater stress distribution and adhesion within the matrix. Thus, SEM analysis indicates that the treatment indeed improves the structural integrity and purity of the fiber so that it could be well suited to high-performance applications where consistent properties are essential. Figure 3 shows the morphology of untreated and treated kenaf fibers.

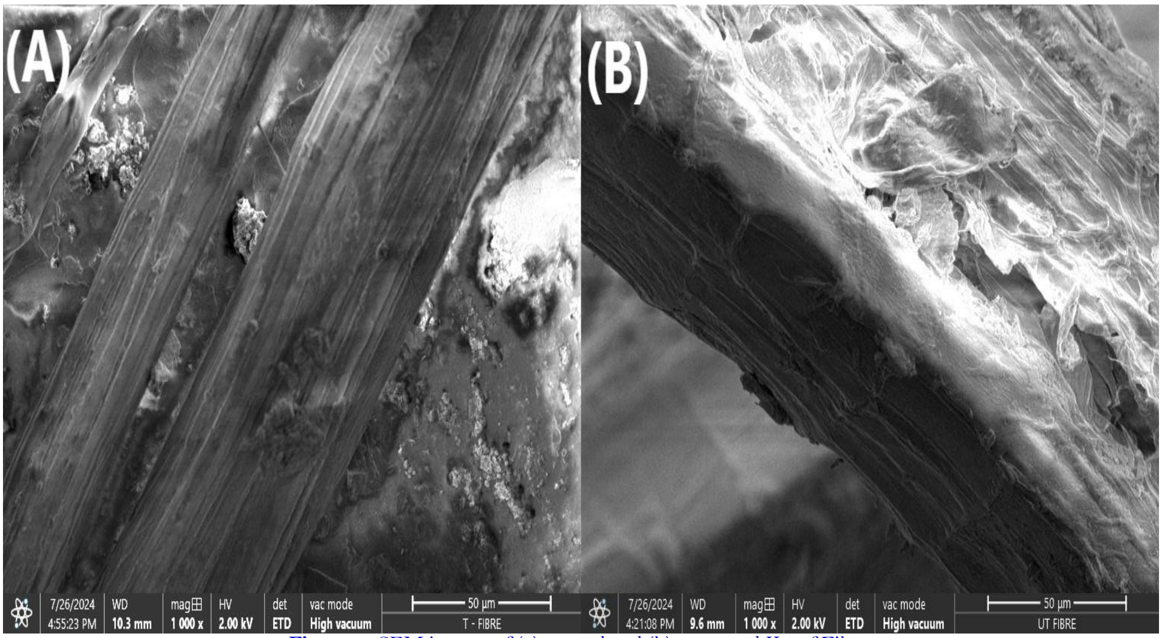

Figure 3. SEM images of (a) treated and (b) untreated Kenaf Fiber.

3.3.2. EDX Analysis

Energy Dispersive X-Ray Spectroscopy (EDX) revealed crucial insights into the manner in which different treatments altered the elemental composition of the kenaf fiber. In conducting analysis on the untreated fibers, sharp peaks appeared for carbon (C) and oxygen (O), which are inherent to the organic structure of plants. The presence of smaller peaks for elements like calcium (Ca), sodium (Na), and chlorine (Cl) indicated the presence of non-cellulosic impurities such as mineral deposits and salts.

After treatment, the treated fiber's EDX spectra still showed strong carbon and oxygen peaks but were greatly reduced in intensity for several of the minor elements, confirming the purification. Quantitative analysis highlighted the changes: The carbon content slightly decreased from 58.82% in the untreated fibers to 57.04% in treated fibers, owing to the removal of organic substances considered lignin and hemicellulose. Simultaneously, the oxygen content increased from 39.67% to 40.29%, attributed to better exposure of the oxygen-rich cellulose. Drastic decreases in calcium (from 1.07% to 0.10%) and sodium (from 0.32% to 0.25%) were recorded, supporting the thorough removal of mineral and salt impurities during chemical treatment.

Such compositional changes would majorly affect the quality and performance of the fiber. The impurities indicate formation of less clean fibers, which are richer in cellulose but also show higher elemental disparities. Such disparities within the fibers guarantee inconsistent material properties that are undesirable for applications requiring high performance, whether in composites or textile forms. Also, the slight increase in oxygen quantity indicates an improvement in fiber reactivity and bonding capabilities, which translates to better compatibility with polymer matrices in composite materials. The better-purified fibers will be better positioned to carry out and transfer stress, thus performing better mechanically with fewer defects.

3.4. TGA Analysis

Thermogravimetric analysis is utilized to assess the stability of temperature-sensitive materials. It essentially measures weight loss as a function of temperature. Therefore, TGA results obtained on untreated and treated kenaf fibers serve as valuable resources for studying thermal decomposition behaviors and how they are affected by chemical treatment, as shown in Table 1. The TGA curves indicate the main stage of decomposition for both types of fibers between 200 °C and 400 °C. This temperature range is associated with the maximum rate of weight loss; organic substances such as hemicellulose, cellulose, and lignin begin to deteriorate. A significant difference emerges at this point the treated fibers undergo slightly less weight loss than the untreated ones during this temperature range. This strongly suggests that the chemical treatment has successfully eliminated or modified non-cellulosic materials such as hemicellulose and lignin, which are thermally less stable and typically decompose at lower temperatures. These findings are consistent with recent studies. For instance, Ebrahimi et al. (2024) observed treatment-induced removal of non-cellulosic components, leading to an increase in the thermal stability of natural fibers.

Following the initial rapid decomposition between 250°C and 400°C, a secondary weight loss occurs more slowly between 400°C and 600°C. This stage corresponds to the degradation of more stable residual compounds, such as charred substances. At this stage, treated fibers drop at a slower rate than untreated ones, which would either imply that the char residues formed are more thermally stable or simply that major chemical treatment results in lower char yield. Such stabilization indicates that at least some of the fibers can be used in strong heat environments, increasing their applicability for uses requiring sustained thermal resistance, such as filtration.

During the last decomposition stage, there was a gradual weight loss of the two sets of fibers from 600°C to 800°C. At last, the treated fibers left a slightly smaller amount of residue. This again supports the supposition that the chemical treatment aided in removing impurities and reduced total carbon to a small extent, which would then make the remaining residues more prone to thermal degradation.

Table 1. TGA results for untreated and treated kenaf fibers.

Fiber	Initial degradation (°C)	Max degradation (°C)	Residual weight	Comments
Untreated Kenaf	240°C	280°C	Higher	Shows significant degradation of hemicellulose, cellulose, and lignin.
Treated Kenaf	240°C	280°C	Lower	Slightly less degradation in the primary decomposition phase, enhanced thermal stability.

3.5. Water Quality Assessment and Filtration Efficiency

The data from Table 2 show that kenaf fiber-based filters are effective in removing various contaminants. Among contaminants removed by the filters were turbidity (99.98%), phosphate (96.85%), and chloride (92.76%). These high removal rates are consistent with the properties of kenaf fibers, which are known to be highly effective at adsorbing heavy metals and other pollutants. This observation is supported by Razak et al. (2020), who indicated that chemically modified kenaf fibers conform to the Langmuir Adsorption Isotherm, whereby a monolayer of adsorbate molecules is formed on the surface of the adsorbent. Strengthened by Hossain, Subbiah, et al. (2022), who found kenaf fiber filters to strongly adsorb organic pollutants, the findings also support the observed 78.44% removal of TOC in this study.

The closeness of COD (80%) and BOD (73.51%) reduction values to recorded values is noteworthy, wherein Singh, Mukhopadhyay, and Rengasamy (2022) observed over 85% COD removal for oily wastewater via fibrous coalescence filtration systems (like kenaf). This indicates the need for additional treatment methods to enhance kenaf fiber performance, such as carbonization or chemical modifications.

The removal efficiencies of nitrate (89.51%) and phosphate (96.85%) seem to be on par with those of biochar-based filters in the studies of Poudyal and Tatarchuk (2024), where ion capture follows porous fibers with an intrafiber wicking mechanism. The high removals are probably influenced by the cation exchange properties of kenaf. TDS removal (73.51%) and total hardness reduction (35.67%) are, however, only moderate, which simply means that kenaf-based filtration must be paired with complementary processes to address mineral content.

Table 2. Water quality results for kenaf fiber filters.

Parameter	WHO standard	Untreated	Treated	Removal efficiency (%)
Chloride (mg/l)	100	150.32	10.88	92.76
Nitrates (mg/l)	10.0	125.78	13.20	89.51
Phosphate (mg/l)	15.0*	28.56	0.900	96.85
BOD (mg/l)	60.0*	92.50	24.50	73.51
COD (mg/l)	75.0*	275.00	55.00	80.00
Total Hardness (mg/l)	100	140.75	90.55	35.67
TDS (mg/l)	500	380.40	100.75	73.51
pH	6.5-8.5	9.45	7.65	-
Turbidity (NTU)	5.0	95.60	0.015	99.98
Total Organic Carbon (TOC) (mg/l)	5.0	58.45	12.60	78.44

Note: * Indicates the values for Phosphate, BOD, and COD are not global WHO drinking water standards but rather regional\country-specific standards.

3.6. Porosity and Flow Rate of Kenaf Fiber Filters

From the porosity and flow rate results (Table 3), it is observed that treated kenaf fibre filters have greater porosity and flow rate than untreated fibres. More specifically, porosity is 8.7% and flow rate is 3.33 ml/min for the treated type, while 5.2% and 1.33 ml/min, respectively, for the untreated type. These findings on increased filtration efficiency with treatments agree with Soloveva, Solovev, Kharchuk, Belousova, and Talipova (2021), who stated that fibrous filter porosity in the range of 7-9% drastically improves contaminant capture whilst still retaining the acceptable permeability.

Kenaf fiber filters, however, suffer from lower levels of permeability compared to advanced porous ceramic filters with 78.11% porosity, as investigated by Zhu, Zhu, Hu, and Wang (2024), thus possibly hindering their commercial-scale application. The ills of low porosity and slower flow rate could be remedied by structural modification, such as nanocoating or composite reinforcement, as was presented by Wang et al. (2022) in their work on porous fibrous filtration.

Table 3. Flow rate and physical properties of kenaf fiber-based filters.

Sample	Volume filtered (ml)	Time (Min)	Flow rate (ml/Min)	Porosity (%)
Untreated	80	60	1.33	5.2
Treated	200	60	3.33	8.7

3.7. Sustainability and Biodegradability

The sustainability and biodegradability properties of Kenaf fiber filters make them an environmentally viable alternative to synthetic and ceramic filter systems. This stems from their nature-based origin and assured short decomposition times. It has been established through studies that untreated Kenaf fibers would completely degrade within 90 days in a natural soil environment (Hossain, Subbiah, et al., 2022). This way, rapid biodegradability reduces the threat of a long-lasting environmental impact.

Untreated fibers are therefore highly biodegradable but can be modified chemically to make them more durable. The literature states that polymer reinforcement of kenaf fibers appears to extend their time of degradation without sacrificing environmental considerations, thus allowing for a tradeoff between longevity and sustainability.

Plant-based systems such as kenaf represent a major reduction in carbon emissions, quantified as the carbon footprint. According to research by Poudyal and Tatarchuk (2024), plant-based filters reduce carbon emissions by about 40 percent, compared with synthetic filters, largely because of less energy consumed during manufacturing and disposal. The main problem is that microbial degradation takes place in conditions with high humidity. Future research could examine hybrid systems that use kenaf fibers in conjunction with biodegradable coatings that improve the longevity of said fibers without diminishing their green characterization.

3.8. Limitations and Challenges

Although kenaf fiber filters bear loads of promise, their wide application is hindered by some inherent drawbacks. A major issue is, for instance, longevity; natural fibers are prone to degradation over time, leading to the loss of structural integrity of the filter. Another main challenge is scalability. Efforts are needed to optimize processing techniques and the materials used to reinforce the product without compromising the cost of mass production. Consequently, future research should focus on fiber treatments that enhance durability while maintaining the natural biodegradability of the material. Striking this balance between longevity and environmental sustainability is essential.

4. CONCLUSION

Kenaf fiber water filters have emerged as a compelling alternative solution to plant-based environmentally friendly filters. Characterized by absorption qualities, turbidity, and chemical contaminants can be chemically separated with maximum adsorptive capacity and phenomenal porosity of 20 nm to 98 nm. This means that dissolved substances—nitrate, phosphate, and total dissolved solids can be removed, making this system very attractive for rural and urban water purification. Apart from the environmental benefits, these filters have very little environmental impact in terms of waste and are low-waste systems.

Nevertheless, it does not mean the path to widespread adoption is without some impediments. Limitations here mainly revolve around durability concerns, as these fibers tend to degrade over long periods, and issues of scalability concerning large-scale production. Therefore, future perspectives have to consider further research into enhancing structural integrity, improving microbial removal efficiency, and engendering the best production methods. For the filter to thrive for the long haul, it will have to be integrated into decentralized water treatment, working on a platform of policy incentives. Then, of course, promotion through collaborative efforts between researchers, industries, and policymakers. Solving these challenges will allow kenaf fiber filters to chart their course toward untangling the ever-present water problems worldwide, all while supporting environmental sustainability.

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REFERENCES

Abdullah, H. H., Zakaria, S., Anuar, N. I. S., Salleh, K. M., & Jaafar, S. S. (2020). Effect of harvesting time and water retting fiber processing methods on the physico-mechanical properties of kenaf fiber. *BioResources, 15*(3), 7207-7222. https://doi.org/10.15376/biores.15.3.7207-7222

Austin, C. C., Mondell, C. N., Clark, D. G., & Wilkie, A. C. (2024). Kenaf: Opportunities for an Ancient Fiber Crop. *Agronomy, 14*(7), 1542. https://doi.org/10.3390/agronomy14071542

Bhambure, S. S., Rao, A. S., & Senthilkumar, T. (2021). Characterization of control and chemically modified Kenaf fiber. *Journal of Natural Fibers, 19*(15), 10320-10330. https://doi.org/10.1080/15440478.2021.1993500

Ebrahimi, P., Koosha, M., Hamedi, S., Vatankhah, E., & Shidpour, R. (2024). Surface functionalization of kenaf fibers with lauroyl chloride: Effects of alkaline pretreatment method. *Cellulose Chemistry and Technology, 58*(1-2), 115-123.

Guo, R., Liu, H., Yang, K., Wang, S., Sun, P., Gao, H., . . . Chen, F. (2020). β-Cyclodextrin polymerized in cross-flowing channels of biomass sawdust for rapid and highly efficient pharmaceutical pollutants removal from water. *ACS Applied Materials & Interfaces, 12*(29), 32817-32826.

Hossain, M. M., Siddiquee, S., & Kumar, V. (2021). Water sources derived bio retting effect on kenaf fiber compositions. *Journal of Natural Fibers, 19*(14), 9396-9409. https://doi.org/10.1080/15440478.2021.1982829

Hossain, M. M., Subbiah, V. K., & Siddiquee, S. (2022). Augmented retting effect on kenaf fibers using alkalophilic pectinase-producing bacteria in combination with water solvents. *Applied Sciences, 12*(14), 7136. https://doi.org/10.3390/app12147136

Ibrahim, N. A. N., Awang, M., & Jusoh, S. M. (2020). An investigation of kenaf plant fibers as reinforcements in interwoven kenaf/polyethylene terephthalate (PET)/epoxy hybrid green composites. *Universiti Malaysia Terengganu Journal of Undergraduate Research, 2*(2), 23-32. https://doi.org/10.46754/umtjur.v2i2.110

Judawisastra, H., & Refiadi, G. (2022). Permanganate treatment optimization on tensile properties and water absorption of Kenaf fiber-polypropylene biocomposites. *International Journal of Automotive and Mechanical Engineering, 19*(1), 9623-9633. https://doi.org/10.15282/ijame.19.1.2022.23.0742

Kausar, A. (2024). Sustainable membrane technology for water purification—Manufacturing, recycling and environmental impacts. *Journal of Polymer Science and Engineering, 7*(1), 5976. https://doi.org/10.24294/jpse.v7i1.5976

Liu, J., Liu, L., Huang, Z., Fu, Y., & Huang, Z. (2020). Contaminant removal and optimal operation of bio-slow sand filtration water treatment based on nature-based solutions. *Polish Journal of Environmental Studies, 29*(2), 1703-1713. https://doi.org/10.15244/pjoes/109728

Mahmoud, A. R. A. (2021). *Effectiveness of bank filtration for water supply in arid climates.* Boca Raton, FL: CRC Press.

Mishra, M., Mittal, A., Negi, G. S., Singh, P., Kaur, S., Mongal, B. N., . . . Karthikeyan, R. (2024). *Green synthesis of nanocomposite membranes for sustainable water filtration.* Paper presented at the E3S Web of Conferences, EDP Sciences.

Morad, S., Abo Ali, S., Diab, L., Abedelrahman, R., Amar, F., Asli, S., . . . Diab, M. (2023). Carbon filtration: Harnessing cotton's power to purify drinking water. *Water Quality Research Journal, 58*(4), 301-311. https://doi.org/10.2166/wqrj.2023.013

Mustapha, R., Mustapha, S. N. H., Suriani, M., Ruzaidi, C., & Awang, M. (2021). Water absorption behaviour of epoxy/acrylated epoxidized palm oil reinforced hybrid kenaf/glass fiber montmorillonite composites. *Journal of Physics: Conference Series, IOP Publishing, 2080*(1), 012013.

Narkpiban, K., & Poonsawat, T. (2020). Optimizing cellulose extraction from kenaf (Hibiscus Cannabinus L.) fiber by selective retting and hydrothermal pretreatment. *Journal of Natural Fibers, 19*(2), 700-713. https://doi.org/10.1080/15440478.2020.1758982

Pachappareddy, C., Padhy, C. P., & Pendyala, S. (2024). *The impact of filler made of acacia concinna pods and fiber treatment on the water absorption properties of kenaf fiber hybrid composites.* Paper presented at the Journal of Physics: Conference Series, IOP Publishing.

Poudyal, A., & Tatarchuk, B. J. (2024). NaCl aerosol filtration over filter media with intrafiber porosity: Can filtrate capacity be increased by wicking into this pore volume? *Nanotechnology, 35*(48), 485704. https://doi.org/10.1088/1361-6528/ad7140

Razak, M. R., Yusof, N. A., Aris, A. Z., Nasir, H. M., Haron, M. J., Ibrahim, N. A., . . . Kamaruzaman, S. (2020). Phosphoric acid modified kenaf fiber as green adsorbent for the removal of copper ions. *Reactive & Functional Polymers, 147*, 104466. https://doi.org/10.1016/j.reactfunctpolym.2019.104466

Sidik, M., Mohamed, R. M., Baba, N. B., & Mohd, A. (2022). Water absorption study on kenaf/ABS composites. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, 99*(2), 180-186. https://doi.org/10.37934/arfmts.99.2.180186

Silva, A. P., Lemos, M. F., & Monteiro, S. N. (2021). Thermal and chemical characterization of kenaf fiber (Hibiscus cannabinus) reinforced epoxy matrix composites. *Polymers, 13*(12), 2016.

Singh, C. J., Mukhopadhyay, S., & Rengasamy, R. S. (2021). Fibrous coalescence filtration in treating oily wastewater: A review. *Journal of Industrial Textiles, 51*(3_suppl), 3648S-3682S. https://doi.org/10.1177/15280837211040863

Soloveva, V., Solovev, S. A., Kharchuk, S. I., Belousova, L. A., & Talipova, A. R. (2021). Determination of the effective porosity of a single filter fiber. *Journal of Physics: Conference Series, IOP Publishing, 2094*(2), 022075. https://doi.org/10.1088/1742-6596/2094/2/022075

Sudiyani, Y., Widmer, K., Andreas, A., Tasfiyati, A. N., Athaillah, Z. A., Muryanto, M., . . . Kang, S. (2022). Impact of gravity-driven membrane filtration water treatment systems on a rural school in Indonesia. *Sustainability, 14*(21), 13733. https://doi.org/10.3390/su142113733

Wang, L., Zhao, X., Wu, J., Sun, Y., Wu, M., & Zhang, K. (2022). CFD-Based spherical fiber filter structure performance simulation research. In Modern Management based on Big Data III. In (pp. 447–455). Cham, Switzerland: IOS Press

Zhu, J., Zhu, R., Hu, Y., & Wang, Z. (2024). Mullite fiber porous ceramic with high quality factor for high-temperature PM filtration. *Journal of the European Ceramic Society, 44*(4), 2630-2637. https://doi.org/10.1016/j.jeurceramsoc.2023.11.064