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Decolorization of cellulose-based post-consumer textile waste in a sequence involving sodium hydroxide, chlorine dioxide, and hydrogen peroxide

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Abstract Decolorization of post-consumer, cellulose-based textile waste is crucial for high-quality fiber-to-fiber recycling. However, this process remains challenging due to the heterogeneous composition of textile waste and the presence of multiple dye classes and additives. In this study, mixed cotton and viscose (regenerated, man-made cellulose) post-consumer textile wastes were treated using a decolorization sequence comprising sodium hydroxide, chlorine dioxide, and hydrogen peroxide. Despite the complexity of both textile waste materials, the decolorization sequence led to significant improvements in optical properties, with brightness increasing from 10% to 74% for cotton and from 7% to 77% for viscose. The E- and D-stages were identified as the main contributors to the improvements in brightness. In addition, it was found that the viscosity of the cellulosic material, especially that of cotton, can be optimized towards specific target values by adjusting process conditions in both the D-stage and P-stage of the decolorization sequence. The introduction of magnesium in the P-stage enabled more stringent control of decolorization, resulting in improved intrinsic viscosity and reduced dissolution of organic material, measured as the chemical oxygen demand and total organic carbon.

Keywords: Post-consumer textile waste • Cotton • Viscose • Decolorization • Brightness • Intrinsic viscosity • Alkaline treatment • Chlorine dioxide • Hydrogen peroxide.

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Introduction

In recent decades, textile garment production and consumption have increased rapidly due to declining prices, fast fashion, and a growing global population, leading to unsustainable textile use (European Parliament 2025). Fast fashion brands, such as Temu, SHEIN, Zara, and H&M, now release numerous collections annually, prompting consumers to make frequent purchases and to discard the clothing after limited use.

The European Environmental Agency (2022) ranks textiles as the fifth most environmentally problematic product category. Textile consumption in the EU increased from an average of 17 kg per person in 2019 to 19 kg per person in 2022. At the same time, around 12 kg of clothing per person is discarded every year. Less than half of the used garments are collected for reuse or recycling, and only about 1% are recycled into new clothing (European Parliament 2025). Approximately 87% of discarded clothes are exported outside the EU, where they are incinerated or sent to landfills. To reduce exports and increase recycling, the EU's Waste Framework Directives require separate textile collection for reuse and recycling as of January 1, 2025 (Michaliková 2024). This has highlighted the necessity to advance textile recycling processes and explore the potential of utilizing recycled cellulose-based waste textiles as raw materials for the production of man-made cellulosic textile fibers. However, recycling textile waste is complicated, especially in relation to the decolorization of post-consumer textiles, which raises challenges due to its heterogeneous composition and the variety of dyes and additives used in textile manufacturing.

In a recently published literature review, Periyasamy and Harlin (2025) pointed out that decolorization is a crucial step in enabling the fiber-to-fiber textile recycling process. A few decolorization studies of cotton textile samples dyed with specific dyes have been performed using various chemicals and techniques. Määttä et al. (2019) concluded that the most efficient treatment sequence involves a hot caustic extraction stage (HCE) followed by decolorization using a sequence that includes ozone (Z), hydrogen peroxide (P, H_2O_2), and acid treatment (A), this sequence achieved ISO brightness levels >90% for cotton dyed with reactive dyes. In a related study using a similar decolorization sequence for pre-consumer cotton waste, the decolorized textiles were subsequently dissolved and regenerated into new textile fibers through a cellulose carbamate process (Määttä et al. 2021). In another study, an acid, dithionite (Y), and hydrogen peroxide sequence was shown to be effective in removing different types of dyes from cotton fabrics (Bigambo et al. 2020). An ISO brightness of between 65% and 87% was achieved when this sequence was applied to cotton that was dyed with reactive dyes and post-consumer denim jeans. In a complementary study, it was concluded that more than 97% of vat and sulfur dyes applied to cotton fabrics could be removed using the same AYP sequence (Bigambo et al. 2021). In contrast, it was shown that pigment prints were removed more efficiently using an AEP sequence (Bigambo et al. 2021). Ozone (Z) treatment in one stage has also been investigated for the removal of reactive dyes, with the highest level of color removal (98% of the original color) being achieved at pH 5 (Powar et al. 2021). Further research has explored the use of reducing and oxidizing agents for decolorization of reactive dyed cotton textiles, with potassium permanganate achieving the highest CIE whiteness of 79 and sodium dithionite together with hydrogen peroxide achieving a CIE whiteness of 74 (Li et al. 2022). Moreover, Fenton's reagent (H_2O_2/Fe^{2+}) has been investigated as an alternative to alkaline hydrogen peroxide for textile decolorization, achieving 62% color removal for black and 73% for blue reactive dyes (Meurs et al. 2024). Note that most of the studies mentioned above have investigated the decolorization efficiencies of various chemicals/treatments on cotton fabrics dyed with a specific dye. However, a recent study (Ronge 2025) investigated the decolorization of post-consumer, cellulose-based textile waste (comprising cotton and viscose of mixed colors). Iterative development and evaluations of a decolorization sequence for these textile wastes were conducted, utilizing alkali, oxidative, and reductive treatments with sodium hydroxide, chlorine dioxide (D), hydrogen peroxide, ozone, and sodium dithionite. The D-stage proved to be more effective than the Z-stage for brightness enhancement at lower oxidative equivalents (OXE). For both cotton and viscose, the D-stage increased brightness by 0.03% per OXE, while the Z-stage achieved an increase of 0.02% per OXE. Furthermore, the findings indicated that the EYDP sequence was the most effective decolorization method for cotton, while the EDP sequence was optimal for viscose, increasing the brightness of cotton from 14% to 80%, and increasing the brightness of viscose from 7% to 76%.

This study aims to optimize the decolorization efficiency of a three-stage sequence, EDP, under various process conditions for two post-consumer, cellulose-based textile wastes of various colors and origins, including cotton and viscose (regenerated, man-made cellulose). Furthermore, the study evaluates the effects of chemical treatments on intrinsic viscosity and other properties that are relevant to textile recycling.

Materials and methods

Chemicals and textile wastes

Sodium hydroxide (1 M and 5 M NaOH), sulfuric acid (2 M H₂SO₄), and magnesium sulphate (MgSO₄) were purchased from Fisher Chemicals, Scharlab, and Chem-Lab, respectively. Aqueous chlorine dioxide (ClO₂) was collected from a chlorine dioxide plant at a pulp mill, and hydrogen peroxide, Eka® HP T49, was obtained from Nouryon's Bohus site in Sweden.

The post-consumer textiles used in this study were sorted by Wargön Innovation (Trollhättan, Sweden) into two fractions: cotton and viscose. Buttons and zippers were removed before the textiles were cut into ~2×2 cm pieces. The textile pieces were then shredded in a Mesdan Laboratory Shredding Machine 337S at the Swedish School of Textiles in Borås. The conditions used for shredding were as follows: feeding velocity, 1 m/min; main drum velocity, 900 rpm; worker velocity, 20 rpm; and suction speed, 3,000 rpm. The textiles were passed through the machine twice to achieve a satisfactory degree of fiber separation.

Decolorization procedure

The decolorization was performed in sealed polyethylene bags at a fiber consistency of 10%, with a temperature of 70°C or 90°C for 120 minutes. Deionized water was mixed with sodium hydroxide or sulfuric acid, and thereafter mixed with aqueous chlorine dioxide or hydrogen peroxide. The solution was then thoroughly mixed with the fibers in the polyethylene bag, which was sealed quickly and placed in a water bath at the selected temperature. The bags were gently pounded two more times during the first 10 minutes of the decolorization process. After 2 hours, the polyethylene bag was cooled to room temperature, and the fibers were filtered through a 112-μm nylon filter on a Büchner funnel. The filtrate was collected and analyzed for its final pH and residual chemicals. The textile sample was then washed three times at a fiber consistency of 2% using hot deionized water (~50°C).

Characterization and analysis procedures

Brightness was analyzed according to a modified version of ISO standard 2470-1:2009 (d/0°; C/2°) using the Technidyne ColorTouch X ISO spectrophotometer. Brightness was measured on the wire side of a small sheet, which was prepared using a Büchner funnel equipped with a 112-μm nylon filter, pressed at 2.8 bar for 2 minutes and then left to dry in the dark overnight at room temperature.

The intrinsic viscosity of the fibers was measured following a modified version of ISO standard 5351:2010. The time for shaking the sample in the cupri-ethylenediamine solution was extended compared to the standard, so as to dissolve completely the cellulosic fibers. The samples were shaken for 2 hours, left overnight, and then shaken again the next day for an additional 2 hours before filtration. The solution was filtered without vacuum through a pre-weighed 22-μm nylon filter, to remove undissolved material. The filter with the remaining residues was washed with deionized water and then dried in a ventilated oven at 105°C until totally dry. The filter was weighed again to obtain the weight of the undissolved fibers. To calculate the viscosity, the corrected weight of the dissolved fibers was used.

Fourier Transform Infrared Spectroscopy analyses were conducted in the FTIR Spectrum One spectrometer (Perkin Elmer), which was equipped with an ATR (attenuated total reflectance) module to identify the material of the non-decolorized fibers.

Residual levels of H₂O₂ and ClO₂ in the filtrates were determined by iodometric titration using 0.05 M sodium thiosulfate (Merck). The chemical oxygen demand (COD) in the filtrates was determined with a Hach Lange DR2800 VIS spectrophotometer according to the Dr. Lange Classic Cuvette Test, after filtration through a 0.45-μm nylon syringe filter. The total organic carbon (TOC) in the filtrates was measured according to SS-EN ISO 20236 and SS-EN 1484 using the Shimadzu TOC-L CPH instrument equipped with a TNM-L-module and adsorbable organic halogen (AOX) was measured according to SS-EN ISO/IEC 17025:2018 using a Trace Elemental Instrument (Xplorer).

Results and discussion

In this study, decolorization of post-consumer, cellulose-based textile wastes, i.e., cotton and viscose of mixed colors, was investigated using an EDP sequence. Each stage of the sequence was optimized in a stepwise manner

to enhance the overall efficiency and effectiveness of the decolorization process with respect to brightness and intrinsic viscosity.

Alkaline (E) decolorization

The effectiveness of the alkaline treatment was examined for the two types of post-consumer waste textiles, cotton and viscose, by treating them with different dosages of NaOH at a fiber consistency of 10%, at 90°C for 120 minutes. The brightness levels and viscosities of the samples are presented in Fig. 1. The brightness levels of the samples increased with increasing NaOH dosage; the viscose sample reached a brightness of ~50% (+43 brightness units) and the cotton sample reached a brightness of ~40% (+30 brightness units) when 400 kg of NaOH per tonne of textile (4.4% w/w NaOH solution) was applied (Fig. 1a). However, the brightness levels of both the cotton and viscose material showed a pronounced step response with NaOH additions up to about 150 kg/t, beyond which the brightness increased to a lesser extent. The appearances of the textile samples following NaOH treatment at varying dosages are presented in Fig. 2. A significant amount of the dye present in the textile samples detached from both the cotton and viscose fibers and was present in the filtrate. The efficiency of NaOH for cleaving covalent bonds between the dye and the hydroxyl groups of cellulose fibers, such as cotton, has been previously documented (Haule et al. 2014; Wedin et al. 2018; Määttä et al. 2019; Wang et al. 2023). However, those studies typically used significantly higher dosages of NaOH, in the range of 720–2,300 kg/t, in conjunction with higher temperatures.

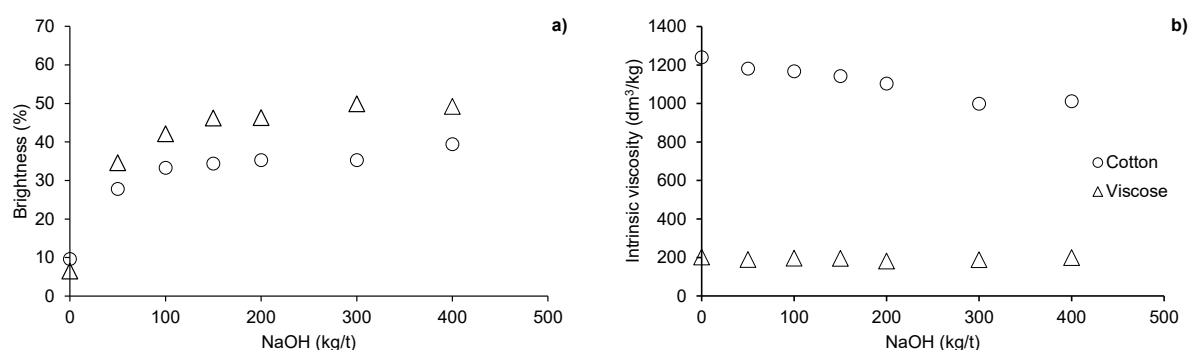


Fig. 1 Impacts of sodium hydroxide (NaOH) dosages on: a) the brightness levels, and b) the intrinsic viscosities of the cotton and viscose post-consumer textile wastes. The conditions used were: fiber consistency of 10%, at 90°C for 120 minutes

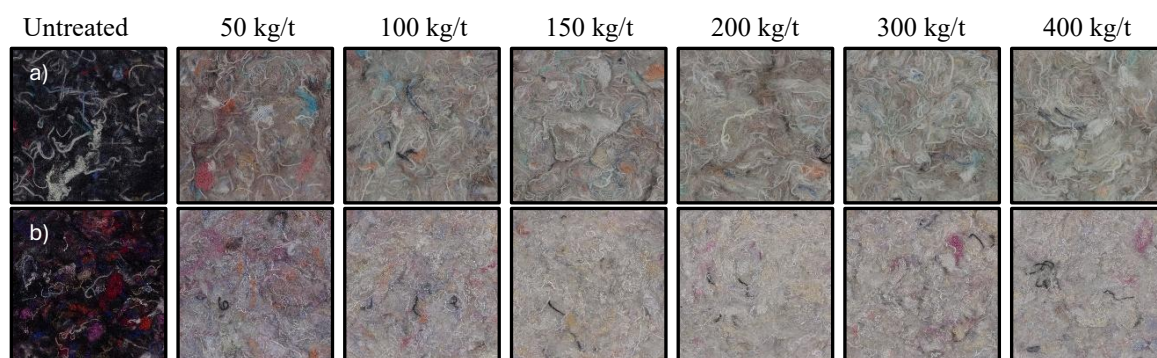


Fig. 2 Photographs of the textile samples for a) cotton and b) viscose following the alkaline treatment stage (E) with different dosages of sodium hydroxide (range, 50–400 kg/t). The conditions used were: fiber consistency of 10%, at 90°C for 120 minutes

As shown in Fig. 1b, the intrinsic viscosity of the cotton textile sample decreased from 1,240 dm³/kg to about 1,000 dm³/kg with increasing NaOH dosage. In contrast, a recent study conducted by Wedin et al. (2018) reported a significantly greater reduction in the viscosity of cotton, from 1,700 dm³/kg to 910 dm³/kg, following alkaline treatment. This substantial decrease in viscosity is likely attributed to the severe conditions employed during the alkaline stage, specifically the use of a 23% w/w NaOH solution, which corresponds to 2,300 kg of NaOH per tonne of cotton, in combination with a higher temperature (100°C). For the viscose textile sample, which is composed of regenerated, man-made cellulose fibers, the intrinsic viscosity was low for the untreated sample (~200 dm³/kg), and remained essentially unchanged during alkaline treatment even with dosages of up to

400 kg NaOH/t. This indicates that the viscose fibers are relatively stable and undergo only limited depolymerization under alkaline conditions, whereas the naturally occurring cellulose in the cotton fibers is more sensitive to alkaline peeling reactions, which decrease the intrinsic viscosity.

As shown in Fig. 3, the content of chemical oxygen demand in the filtrate increased with increasing NaOH dosage for both textiles. The viscose sample generated more COD than the cotton sample, despite its nearly constant intrinsic viscosity. For cotton, the COD increase is probably attributed to the removal of dyes and additives, along with partial degradation of the cellulosic chains. For viscose, the increase in COD is instead likely associated with more-pronounced extraction of dyes and additives, which is in line with the observed increase in brightness (Fig. 1a).

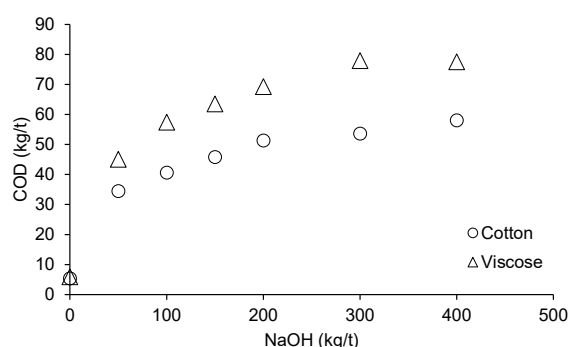


Fig. 3 Impacts of sodium hydroxide (NaOH) dosage on the chemical oxygen demand (COD) of the filtrate from the cotton and viscose post-consumer textile waste samples. The conditions used were: 10% fiber consistency; 90°C for 120 minutes

Although the dosage of NaOH used in the present study, 150 kg/t, is significantly lower than the dosages used in previous studies, there is still a need to improve the sustainability and cost-effectiveness of this stage of the decolorization process. One possible approach is to recirculate the filtrate; however, this necessitates the removal and/or decolorization/degradation of the dyes/additives present in the filtrate. Consequently, the filtrate from the E-stage, which utilized 150 kg of NaOH per tonne of textile, was treated with varying amounts of H₂O₂ at 90°C for 120 minutes. Increasing the dosage of H₂O₂ resulted in enhancement of decolorization and/or degradation of the dyes present in the filtrates, for both the cotton and viscose. This trend is exemplified by the viscose filtrate in Fig. 4. In addition, the effects of H₂O₂ treatment on the COD levels in the filtrates were evaluated. The results indicated a modest reduction in COD, with the values decreasing from 5.6 g/L to 4.7 g/L for the cotton filtrate, and from 7.8 g/L to 6.6 g/L for the viscose filtrate, following treatment with 10 g/L H₂O₂. These findings suggest a method for the recirculation of alkali. However, additional evaluations and optimizations, along with decolorization trials using recirculated alkaline filtrates, are needed to verify the applicability of this approach.

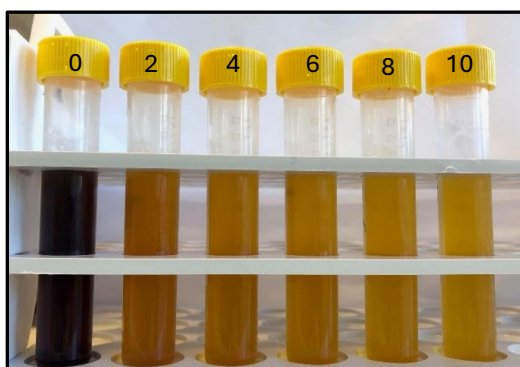


Fig. 4 Appearances of the filtrates from the E-stage (dosage of 150 kg NaOH/t) of the viscose samples treated with various dosages of H₂O₂ (0, 2, 4, 6, 8, 10 g/L) at 90°C for 120 minutes

Chlorine dioxide (D) decolorization

Considering the results of the alkaline treatment, a dosage of 150 kg NaOH per tonne was chosen for the decolorization studies. In a subsequent D-stage, using 11.4 kg ClO₂/t, the effects of the final pH on the brightness and viscosity were investigated (Fig. 5, a and b). The results demonstrate that a D-stage, following an E-stage, is

highly effective in removing the color from both cotton and viscose textile waste samples, resulting in increases of 25 and 23 brightness units, respectively. Furthermore, the brightness levels of the two textile waste samples seem to be relatively unaffected by the final pH in the examined interval (pH 2.3 to 7.5). The standard deviations of the brightness values for the cotton and viscose textile wastes following an ED sequence are approximately 0.6 and 1.4 brightness units, respectively. This variability can be attributed to the heterogeneous nature of the textile waste materials and to the presence of fibers that are almost unaffected by the treatments, possibly representing synthetic fibers (*cf.* Fig. 8 and Fig. 9).

It is clear from Fig. 5b that the intrinsic viscosities of the textile waste samples, especially that of cotton, can be optimized towards a specific target by altering the pH during the D-stage, while maintaining the brightness. The lowest viscosity drop in the D-stage is achieved at a final pH of between 4.0 and 5.5. The decrease in viscosity for the cotton sample both at low pH and high pH is most likely the result of hydrolysis of the cellulose and cleavage of glycosidic bonds. In the case of viscose, which exhibits a low initial viscosity, the variations in viscosity appear to be rather limited.

It is also worth mentioning that the amount of residual ClO_2 for both cotton and viscose increases at final pH values >3 . The COD generated in the D-stage at a final pH of around 3 is low compared with that in the E-stage: 3.5 kg/t for cotton and 2.8 kg/t for viscose, as compared with 46 kg/t and 64 kg/t, respectively, in the E-stage when using 150 kg NaOH/t.

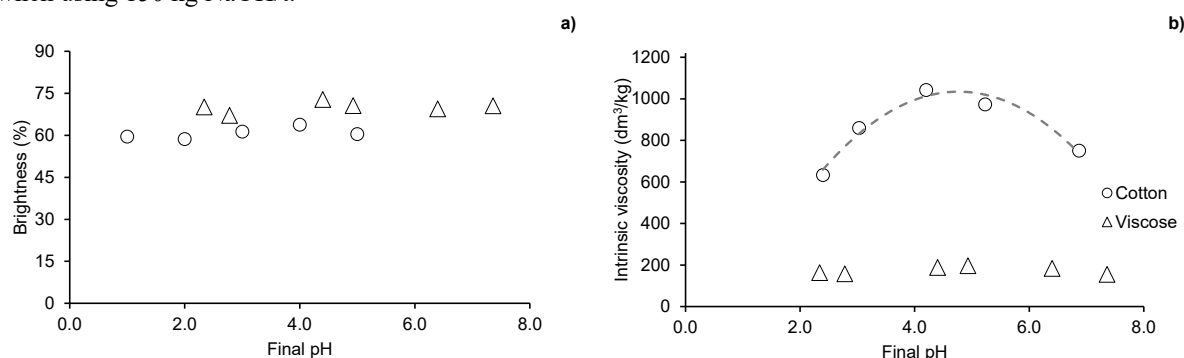


Fig. 5 The effects of final pH on a) brightness, and b) intrinsic viscosity after a chlorine dioxide (ClO_2) stage using 11.4 kg ClO_2 /t following a sodium hydroxide (NaOH) treatment stage (150 NaOH/t), at 90°C for 120 minutes for cotton and viscose waste textiles

The effects of temperatures of 70°C and 90°C in the D-stage were also evaluated for both the cotton and viscose textile samples (data not presented). The findings indicated no significant difference in brightness, although the temperature of 70°C resulted in an increased amount of residual ClO_2 .

The filtrates obtained from the optimized D-stage (final pH 3.0–3.5) for the cotton and viscose materials were analyzed for their contents of adsorbable organic halogens (AOX). The AOX concentration was about 9 mg/L in both filtrates, corresponding to the formation of 0.08 kg AOX/t. These levels are low compared to the amounts formed in the first D-stage during laboratory bleaching of oxygen-delignified softwood kraft pulps, which are in the range of 0.2–0.6 kg AOX/t depending on the incoming kappa number, content of hexenuronic acids, dosage of chlorine dioxide, and the conditions used (Björklund et al. 2002). Note that AOX is an approximate measure of the total amount of chlorinated organic material present and, thus, provides no information about the composition, its origin or the potential environmental effects or toxicities.

Hydrogen peroxide (P) decolorization

As the next step in the decolorization study, the ED-treated cotton and viscose samples (final pH in D-stage is 3.0–3.5) were subjected to further decolorization with alkaline hydrogen peroxide (P), targeting a final pH of approximately 10.5, which is commonly used in kraft pulp bleaching. The effects of H_2O_2 dosages, temperature, and addition of magnesium (Mg^{2+} , added as MgSO_4) on the brightness, viscosity, COD, and residual H_2O_2 were investigated. Magnesium, which is commonly used in conventional kraft pulp bleaching to stabilize H_2O_2 and protect cellulose under alkaline conditions, was included to evaluate whether a similar beneficial effect could be achieved during the H_2O_2 decolorization of cotton and viscose textile wastes.

Increasing the P-stage temperature from 70°C to 90°C led to decreases in the intrinsic viscosity for both the cotton and viscose textile wastes (Fig. 6). At a given temperature, an increase in H_2O_2 dosage from 25 kg/t to 50

kg/t did not generally cause significant changes in the intrinsic viscosity for either type of textile. The presence of magnesium had a beneficial effect in preserving the intrinsic viscosity of the cotton, particularly at 70°C. A positive effect of magnesium was also seen for the viscose sample (Fig. 6b), but on much lower absolute levels, since the incoming viscosity to the P-stage was low (around 200 dm³/kg).

The generation of COD was significantly lower when magnesium was added to the P-stage for both cotton and viscose, under the conditions evaluated in this study (Fig. 7). Moreover, for viscose, there were large differences in COD generation without magnesium between 70°C and 90°C, as well as between 25 H₂O₂/t and 50 kg H₂O₂/t at 90°C. This may be explained by the wide range of NaOH dosages (range, 8–35 kg/t) required to reach a final pH of approximately 10.5. Higher NaOH dosages may lead to increased cellulose degradation and, consequently, higher COD levels in the filtrate, which is in line with the observations made for H₂O₂bleaching of mechanical pulps (Süss 2006).

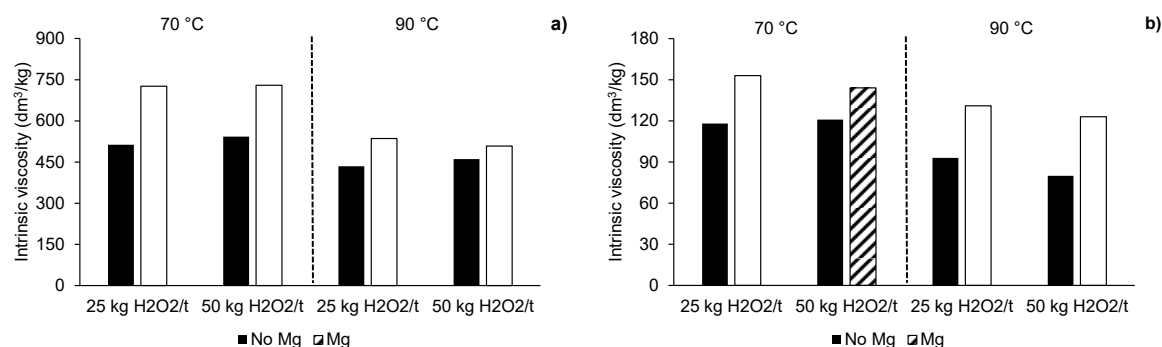


Fig. 6 Intrinsic viscosities for a) cotton and b) viscose textile wastes after the P-stage (final pH ~10.5) at different temperatures and H₂O₂ dosages, with and without Mg²⁺ addition. The conditions used were: P: 25 or 50 kg H₂O₂/t; P_{Mg}: 25 or 50 kg H₂O₂/t with 0.5 kg Mg²⁺/t; 10% fiber consistency; 70°C or 90°C for 120 minutes

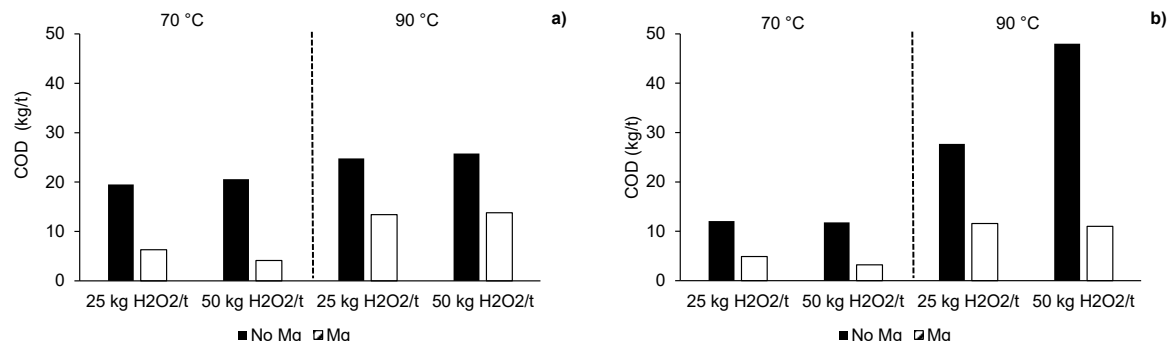


Fig. 7 COD generations in the P-stage (final pH ~10.5) for a) cotton and b) viscose textile wastes at different temperatures and H₂O₂ dosages, with and without Mg²⁺ addition. The conditions used were: P: 25 or 50 kg H₂O₂/t; P_{Mg}: 25 or 50 kg H₂O₂/t with 0.5 kg Mg²⁺/t; 10% fiber consistency; 70°C or 90°C for 120 minutes

For cotton (Fig. 8a), similar brightness levels were obtained with and without magnesium at 90°C and 50 kg H₂O₂/t at a final pH of approximately 10.5. At the lower H₂O₂ dosage (25 kg H₂O₂/t), the addition of magnesium resulted in a slight increase in brightness. In contrast, at 70°C the presence of magnesium had a slightly negative impact on brightness at both 25 H₂O₂/t and 50 kg H₂O₂/t. This can be attributed to the higher levels of residual H₂O₂ remaining after the P_{Mg}-stage (~47% with magnesium, compared with <7% without). For viscose (Fig. 8b), the trends differed somewhat from those of the cotton materials. At 70°C, for example, the presence of magnesium resulted in a higher level of brightness, even though high levels of residual H₂O₂ remained after the P-stage (~54% residual H₂O₂ with magnesium, compared with ~1% without). Several factors may contribute to these differences in brightness, such as the inhomogeneity of the textile waste samples and the fact that H₂O₂ species formed under alkaline conditions (e.g., the hydroperoxyl anion, hydroxyl and superoxide anion radicals) can degrade dyes to different extents, although investigation of these phenomena is beyond the scope of the present work.

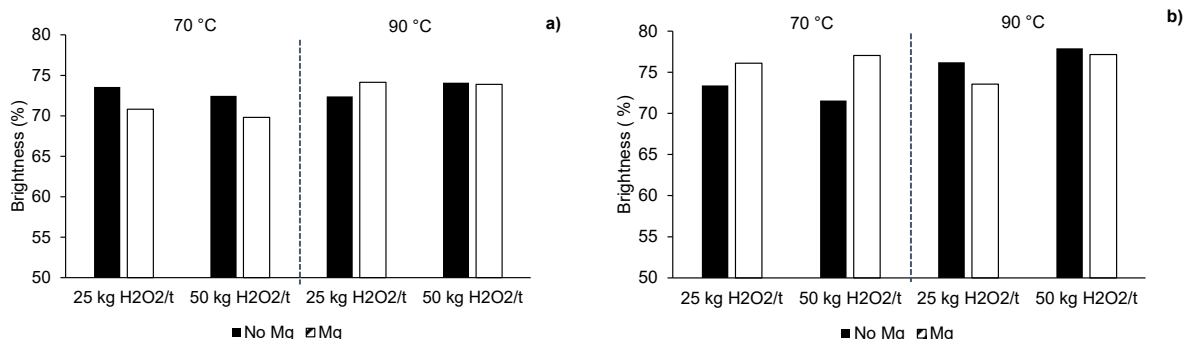


Fig. 8 Brightness levels for a) cotton and b) viscose textile wastes after the P-stage (final pH ~10.5) at different temperatures and H₂O₂ dosages, with and without Mg²⁺ addition. The conditions used were: P: 25 or 50 kg H₂O₂/t; P_{Mg}: 25 or 50 kg H₂O₂/t with 0.5 kg Mg²⁺/t; 10% fiber consistency; 70°C or 90°C for 120 minutes

Decolorization of cotton and viscose post-consumer textile waste using EDP and EDP_{Mg} sequences

Decolorization of cotton and viscose textile waste using an EDP and EDP_{Mg} sequence was performed under the following conditions: E: 150 kg NaOH/t; D: 11.4 kg ClO₂/t; P: 50 kg H₂O₂/t; P_{Mg}: 50 kg H₂O₂/t and 0.5 kg Mg²⁺/t; 10% fiber consistency, 70°C or 90°C for 120 minutes

The brightness and intrinsic viscosity levels measured in samples from each stage in this decolorization sequence are illustrated for both cotton and viscose in Fig. 9, a and b. The E-stage achieved the most substantial increase in brightness for both cotton and viscose, followed by the D-stage, while the P-stage contributed with the lowest brightness increase. The brightness levels of these post-consumer textile wastes in the EDP sequence increased significantly, from 10% to 74% for cotton and from 7% to 77% for viscose. The brightness could, of course, be further improved by including subsequent decolorization stages. Earlier studies of cotton have shown that it is possible to attain higher levels of brightness, in some cases >90% ISO (Määttä et al. 2019, 2021; Bigambo et al. 2020, 2021; Powar et al. 2021; Li et al. 2022; Meurs et al. 2024). However, in those studies, only cotton fabrics dyed with one specific dye were decolorized and, in many of the cases, the chemical dosages were considerably higher. The mixed post-consumer waste used in the present study is a more complicated material to decolorize, since it is a mixture of many different dyes (reactive, direct, and vat dyes of different colors) and other additives.

In the present study, the largest drop in viscosity occurred in the P-stage for both textile samples, although the addition of magnesium in the P-stage preserved to a small extent the viscosity. The decrease in viscosity in the P-stage might be due to the presence of metal ions, which can lead to the formation of hydroxyl radicals and degradation of cellulose. Appropriate management of transition metals through chelation and/or optimized process conditions may help to mitigate these effects. However, in a recently performed study on cotton and viscose textile wastes of mixed colors, the impacts of a Q-stage and the addition of sodium metasilicate on brightness and viscosity levels during an alkaline P-stage were investigated (Ronge 2025). The findings indicated that neither Q-treatment nor the presence of sodium metasilicate had any significant effect on these parameters. Thus, more studies are needed on this topic.

The levels of formation of COD and TOC, stage by stage, in the EDP sequence for cotton and viscose are presented in Fig. 10, a and b. It is clear that the level of formation is higher for viscose compared to cotton, and that the major part of the COD and TOC is formed in the E-stage and P-stages. The addition of magnesium in the P-stage significantly decreases the formation of both COD and TOC. The decrease is more pronounced for viscose than for cotton, most likely due to the higher dosages of NaOH, as discussed earlier.

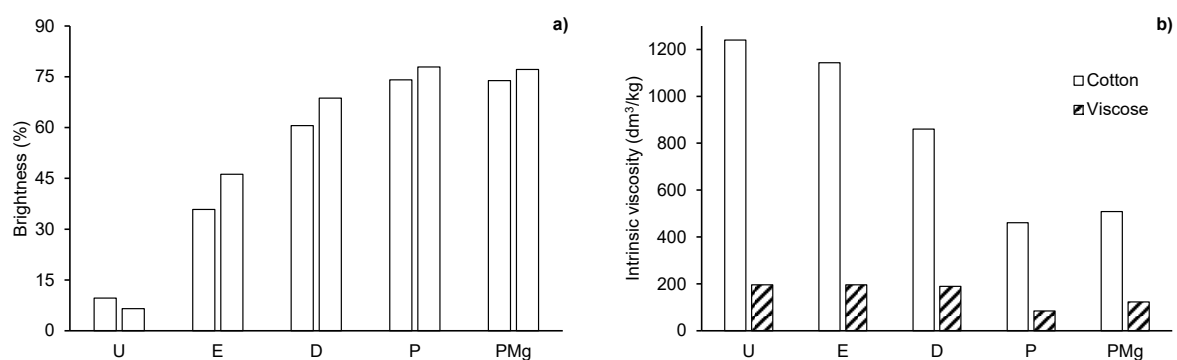


Fig. 9 a) Brightness levels and b) viscosities of the cotton and viscose textile wastes, untreated samples (U), and samples taken after each stage of the EDP and EDP_{Mg} sequences. The conditions used were: E: 150 kg NaOH/t; D: 11.4 kg ClO₂/t; P: 50 kg H₂O₂/t; P_{Mg}: 50 kg H₂O₂/t and 0.5 kg Mg²⁺/t; 10% fiber consistency; 90°C for 120 minutes

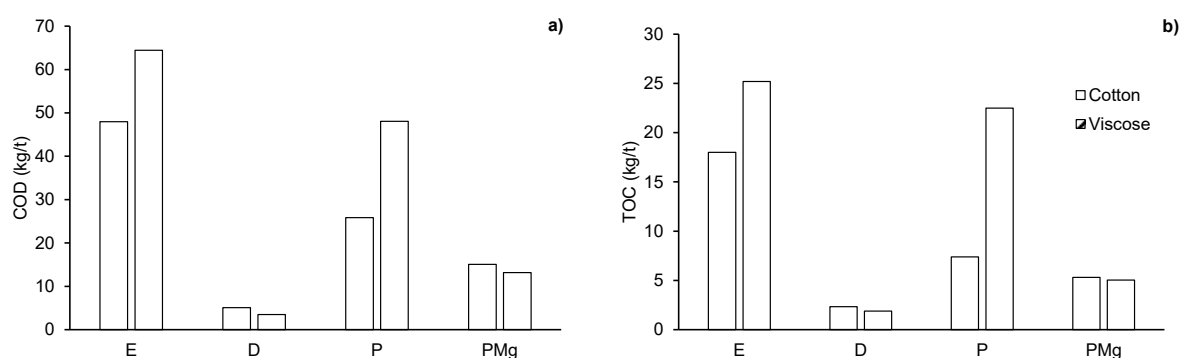


Fig. 10 a) COD and b) TOC levels in the filtrates after each stage of the EDP and EDP_{Mg} sequence for the cotton and viscose textile wastes. The conditions used were: E: 150 kg NaOH/t; D: 11.4 kg ClO₂/t; P: 50 kg H₂O₂/t; P_{Mg}: 50 kg H₂O₂/t and 0.5 kg Mg²⁺/t; 10% fiber consistency; 90°C for 120 minutes

The appearances of the textile fibers after each stage in the sequence, EDP_{Mg}, for the cotton and viscose textile wastes are depicted in Fig. 11 and Fig. 12, respectively.



Fig. 11 Photographs of the cotton samples obtained after each stage in the EDP_{Mg} sequence



Fig. 12 Photographs of the viscose samples obtained after each stage in the EDP_{Mg} sequence

Colorimetric CIELAB ($L^*a^*b^*$) data were collected after each stage in the decolorization sequence for both cotton and viscose (Fig. 13, a and b). As shown in Fig. 13a, there is a pronounced difference in the green–red coordinate (a^* -value) between the untreated cotton and viscose textile wastes (1.6 and 5.5, respectively), despite their similar L^* -values (black–white). This difference in a^* -values is eliminated after the E-stage. The subsequent D-stage results in a further decrease in a^* , accompanied by an increase in L^* , whereas the additional effect of the P-stage on these coordinates is negligible. The untreated textile waste samples exhibit comparable b^* -values (blue–yellow) of approximately -4, which together with L^* increase after the E- and D-stages, while the influence of the P-stage is low (Fig. 13b).

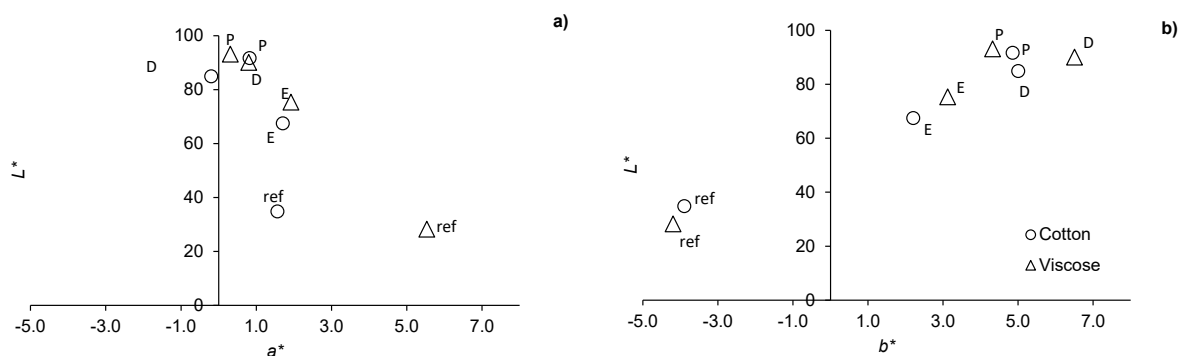


Fig. 13 Lightness (L^*) versus: a) green–red coordinate (a^*); and b) blue–yellow coordinate (b^*) for the cotton and viscose textile wastes after each stage of the EDP_{Mg} sequence. The conditions used were: E: 150 kg NaOH/t; D: 11.4 kg ClO₂/t; P: 50 kg H₂O₂/t; P_{Mg}: 50 kg H₂O₂/t; 0.5 kg Mg²⁺/t; 10% fiber consistency; 90°C for 120 minutes

The cotton and viscose waste samples, as noted after the ED, EDP, and EDP_{Mg} stages, contained some colored fibers (*cf.* Fig. 11 and Fig. 12). These colored fibers were sampled from the material (see Fig. 14) and analyzed for its origin using FTIR. The fibers showed strong absorption at 1,725 cm⁻¹ for ester carbonyl (C=O) bonds and aliphatic C-H stretches, suggesting that the fibers were polyester rather than cellulose. The fibers most likely originate from sewing threads, which are frequently composed of polyester. The contamination of the textile samples with polyester may cause issues during the further processing of these textile samples. However, with appropriate sorting of the textile material and/or separation processes in the manufacturing value chain, the importance of this issue may be diminished.

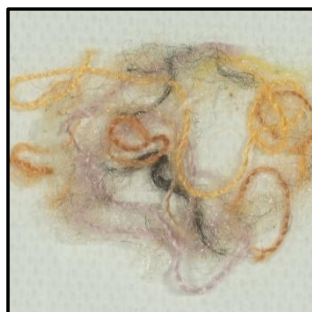


Fig. 14 Photographic image of the colored fibers taken from the EDP_{Mg} decolorized viscose textile waste sample

Overall, this study demonstrates the feasibility of decolorizing two types of cellulose-based textile waste samples of mixed colors and origins, cotton and viscose (regenerated, man-made cellulose), with the achievement of high brightness levels through an EDP or EDP_{Mg} sequence.

Conclusions

The post-consumer, cellulose-based textile wastes investigated, cotton and viscose, were challenging to decolorize because they contained several dye classes (reactive, direct, and vat), as well as various additives. Nevertheless, using a decolorization sequence based on sodium hydroxide (E), chlorine dioxide (D), and hydrogen peroxide (P), with and without Mg²⁺ in the P-stage, the dyes and pigments were efficiently removed. Using this EDP sequence, the brightness was increased from 10% to 74% for cotton and from 7% to 77% for viscose.

The E-stage and D-stage were most effective in improving the brightness levels of the two waste textiles. In addition, the intrinsic viscosity of the textile waste, especially that of cotton, can be optimized towards specific targets by altering the process conditions for the D-stage and P-stage in the decolorization sequence.

The addition of magnesium in the P-stage contributes to a more controlled decolorization process, improving the viscosity to some extent and decreasing the release of organic compounds (measured as the chemical oxygen demand and total organic carbon).

The reduction of chemical dosages, especially that of sodium hydroxide in the E-stage, is vital for improving the overall sustainability and cost-effectiveness of the decolorization process. A potential strategy to achieve this is the removal and degradation of the dyes that are present by utilizing hydrogen peroxide treatment before recirculating the filtrate.

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