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Mini Review

Conserving Energy while Textile Pretreatment

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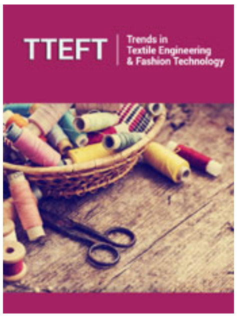
ISSN: 2578-0271



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Submission: April 21, 2023

Published: August 03, 2023

Volume 9 - Issue 1

How to cite this article: Apoorva Misra, Richa Khulbe and Ashok Athalye*. Conserving Energy while Textile Pretreatment. Fashion Technol. 9(1). TTEFT. 000701. 2023. DOI: 10.31031/TTEFT.2023.09.000701

Abstract

Bleaching is an essential process during the pretreatment of natural fibres. The major chemical component used for the oxidative decolourisation of natural impurities from the fibre is Hydrogen Peroxide. The effective performance of this bleaching agent depends on the uniform decomposition of the active component ‘perhydroxy ion’. Conventional processing requires boiling water at a temperature of about 980 °C and maintaining it at this temperature for about 1 hour to achieve the desired result. This is a highly energy-consuming step and tends to adversely impact the environmental carbon footprint. Therefore, the low-temperature bleaching pretreatment is expected to benefit and the researcher’s world over are attempting to devise products and processes to achieve this effect.

Keywords: Natural fibres; Oxidative decolourisation; Colouring component

Introduction

Bleaching involves the removal of an undesired colouring component from the material. This process is widely used in various industries, including textiles, paper and pulp, and food processing, to improve the appearance and quality of products. In the pulp and paper industry, bleaching enhances the whiteness and brightness of paper products. In the textile industry, bleaching removes natural colour from fibre to make it white or achieve a desired shade for dyeing [1].

Bleaching is a necessary pretreatment step in textiles for a variety of reasons. One of the main reasons is to improve the appearance of the fabric by removing any natural or synthetic colour that may be present. This is important because such impurity can affect the final colour of the materials after dyeing. Removing the colour through bleaching leaves the fabric more neutral, allowing for more accurate and consistent dyeing results. In addition to improving the appearance of the fabric, bleaching can also help improve the material’s performance. For example, bleaching helps improve the fabric’s colour fastness, which is its ability to resist fading or colour bleeding when exposed to various environmental factors like sunlight or washing. Bleaching also helps remove any impurities or contaminants present in the fabric, which can affect the strength and durability of the fabric. Thus, bleaching is essential in textiles for achieving the final product’s desired appearance, colour, and performance characteristics.

Hydrogen peroxide as a bleaching agent is accepted globally for its biodegradable nature. However, bleaching often involves using other harsh chemicals and conditions that negatively impact the environment and human health. Generally, a high temperature at the boiling point of water (1000 °C) for about 1 hour is involved. This requires high energy consumption for water heating and then a cooling plant to reduce the temperature for effective effluent treatment [2].

Low-temperature bleaching is an emerging technology that offers a more sustainable and environmentally friendly alternative. This would reduce energy consumption and improve the quality of products by using lower temperatures and milder chemicals. This method is often used for delicate fabrics sensitive to high temperatures and can’t withstand traditional bleaching methods. Some studies found it to improve whiteness without damaging fibre strength, which is not valid for high-temperature bleaching [3].

Significant effects of bleaching on the environment

Bleaching in textiles can have a detrimental impact on the environment as well as on the people who handle the chemicals involved in the process. Here are some of the harmful effects:

Environmental impact: When discharged into water bodies, bleaching chemicals can lead to water pollution and harm aquatic life. Chlorine-based bleaches can also produce toxic by-products, such as dioxins, harming human health and the environment. The use of high temperatures in the scour-bleach process can result in increased energy consumption and carbon emissions, contributing to environmental pollution and climate change.

Health hazards: The chemicals used in bleaching can also harm human health. Exposure to these chemicals can cause skin and eye irritation, respiratory problems, and even more serious health issues with long-term exposure. Workers who handle these chemicals without proper protective equipment are particularly at risk.

Damage to the fabric: Over-bleaching can damage the fibre, making them weaker and more likely to tear or wear out. In addition, some fabrics may be more sensitive to the effects of bleaching and may be damaged even with mild bleaching treatments. High temperatures can cause damage to the fibres in the fabric, leading to reduced strength, durability, and lifespan of the product. Overuse of bleaching agents can also cause yellowing or discolouration of the fabric.

Cost: Bleaching can be costly in terms of the materials and equipment required and the energy needed to carry out the process.

Hydrogen peroxide bleaching

Bleaching textiles with hydrogen peroxide, a potent oxidizing agent, is a popular practice. Hydrogen peroxide is a mildly acidic and transparent liquid with a faint blue colour. Hydrogen peroxide is extremely adaptable because it may be used for various bleaching tasks, such as stain removal, whitening, and brightening on various materials, including linen, cotton, and other synthetic fibres [4].

The mechanism of hydrogen peroxide bleaching involves several steps. First, the hydrogen peroxide molecule breaks down into the water, and a reactive oxygen species called a hydroxyl radical (•OH) in the presence of a catalyst such as a transition metal ion or a chelating agent. The highly reactive hydroxyl radical attacks the chromophores, or the coloured compounds, in the fabric. This process breaks down the chromophores, making them less visible and causing the fabric to appear whiter.

Also, hydrogen peroxide can react with other chemical groups in the fabric, such as carboxylic groups in cellulose fibres, to form peracid species that bleach the fabric. The peracid species can also attack any remaining chromophores, further enhancing the bleaching effect. Adding heat can accelerate the reaction between hydrogen peroxide and the fabric. Still, it can also occur at lower temperatures using a suitable catalyst or activator. Low-temperature hydrogen peroxide bleaching can reduce the risk of fibre damage and increase the efficiency of the bleaching process.

Hydrogen peroxide is effective for low-temperature bleaching for several reasons. First, it is a relatively stable compound that can release oxygen in the presence of certain catalysts, such as heat or light. This means it can slowly break down and release oxygen, which is why it is often used in low-temperature bleaching processes requiring a longer duration [5].

Second, hydrogen peroxide is a relatively mild bleaching agent that can be used on a wide range of fabrics, including delicate fabrics that more aggressive bleaching agents may damage. It can also be used at lower concentrations than other bleaching agents, which reduces the risk of damage to the fabric [6]. Third, hydrogen peroxide has a broad range of antimicrobial properties and effectively removes stains caused by organic matter, such as blood, sweat, and food [7].

Moreover, hydrogen peroxide is preferred over other bleaching agents because of its environmentally friendly nature. It breaks into water and oxygen and thus leaves no harmful residues, unlike other bleaching agents, like chlorine, that give harmful by-products [8].

Low-temperature bleaching technologies

Researchers are continually exploring new and innovative ways to improve the efficiency and sustainability of fabric bleaching processes.

Enzyme bleaching: This type of biological bleaching uses enzymes to break down fabric colour molecules. Enzymes are proteins that catalyse chemical reactions and can be used to remove stains and discolourations in fabrics effectively. Enzyme bleaching can be done at lower temperatures than traditional chemical bleaching, making it a more energy-efficient and environmentally friendly option.

Ultrasonic bleaching: This removes stains and discolourations from fabrics. Ultrasonic bleaching can be done at lower temperatures than traditional chemical bleaching and can be more effective in removing stubborn stains.

Microwave-assisted bleaching: This type of chemical bleaching uses microwave radiation to heat the bleaching solution, which can help reduce the time and temperature needed for bleaching. Microwave-assisted bleaching can be more energy-efficient and cost-effective than traditional chemical bleaching.

Plasma bleaching: This type of physical bleaching uses plasma, or ionized gas, to break down fabric colour molecules. Plasma bleaching can be done at lower temperatures than traditional chemical bleaching and can be more effective in removing stains and discolouration. However, plasma bleaching is a relatively new technology still being developed commercially.

Bleaching activators: Using some activators in peroxide bleaching can make bleaching possible in milder conditions at lower temperatures. Some of these activators are tetraacetylethylene-diamine (TAED), N-[4-(triethylammonium ethyl)-benzoyl]-caprolactam chloride (TBCC) and other lactam-based cationic bleach activators, sodium nonanoyl oxybenzene sulphonate

(NOBS), amino nitriles as well as the derivatives of the cyanamide, thiourea, pentaacetyl glucose (PAG) and tetraacetylhydrazine(TH) are proved to be effective low-temperature bleach activators. All studies showed that these activators might form peroxy acid on reaction with per hydroxyl ion. Peroxyacid is suggested to be a more kinetically reactive species making hydrogen peroxide bleaching possible at lower temperatures [9].

Benefits of low-temperature bleaching

Low-temperature bleaching offers a range of benefits that can improve the quality, durability, and sustainability of textile processing. There are several benefits to using low-temperature bleaching in textile processing, including:

Energy efficiency: Low-temperature bleaching requires less energy than traditional high-temperature bleaching methods. This can result in significant cost savings and can help to reduce the environmental impact of textile processing.

Reduced fibre damage: Traditional high-temperature bleaching can cause damage to the fibres, reducing fabric strength and durability. Low-temperature bleaching can help minimize this damage, resulting in stronger and more durable fabrics.

Improved colour fastness: Low-temperature bleaching can help to improve the colour fastness of fabrics by reducing the stress on the dye molecules in the fabric. This can help to prevent fading and discolouration over time.

Increased safety: Low-temperature bleaching can be safer for workers than traditional high-temperature bleaching, as there is less risk of burns or other injuries from exposure to hot equipment or chemicals.

Environmental benefits: Low-temperature bleaching can help to reduce the environmental impact of textile processing by reducing energy consumption and chemical use. This can reduce greenhouse gas emissions, less water usage, and less chemical waste [10].

Limitations in low-temperature bleaching

While low-temperature bleaching offers several advantages over conventional high-temperature bleaching, some limitations and challenges must be considered.

A. One of the main limitations is the slower reaction rate at low temperatures, which can result in longer processing times and higher energy costs. It typically takes longer than high-temperature methods, as the chemical reactions that cause the bleaching are slower at lower temperatures. This can increase processing time and may require modifications to the production schedule. This can be mitigated by using alternative activation techniques, such as ultrasound or microwave radiation, which can increase the bleaching rate and reduce the processing time.

B. Another challenge is the potential for incomplete bleaching, particularly with certain stains or dyes. In some cases, additional chemical treatments or longer processing times may be necessary to achieve the desired whiteness or colour removal level. Low-temperature bleaching may be less effective than high-temperature methods, particularly for heavily soiled or stained fabrics. This can result in a lower-quality finished product, which may not meet the desired level of whiteness.

C. Low-temperature bleaching can also be more challenging to control and optimize than conventional high-temperature bleaching, particularly concerning the choice of bleaching agents, catalysts, and other process parameters. This can require more specialized knowledge and equipment and additional testing and optimization of the bleaching process. Some types of washing machines or other equipment may not be suitable for low-temperature bleaching, as they may not maintain consistent low temperatures throughout the entire cycle. This can limit the types of fabrics that can be bleached using this method.

D. Low-temperature bleaching may not be suitable for all types of fabrics or garments, particularly those with certain types of finishes or coatings that the bleaching process can damage. Careful testing and evaluation of the fabric or garment are necessary to ensure that the bleaching process will not cause damage or discolouration.

E. Low-temperature bleaching often requires the use of specialized chemicals or equipment, which can increase the cost of production. The longer processing time may also require more labour, increasing prices. These challenges have made it difficult to implement low-temperature bleaching on a large scale in the textile industry. However, ongoing research explores new approaches to address these challenges and improve the feasibility of low-temperature bleaching for textile applications [11].

Thus, the low-temperature bleaching can suit specific applications requiring a gentler, more energy-efficient, and environmentally friendly bleaching process. However, it is essential to carefully evaluate the benefits and drawbacks of this method to determine its suitability for a particular application.

There is a huge need to adopt energy-saving technologies like low-temperature bleaching as the world is stuck with numerous crises related to global warming. We cannot deny the challenges involved in incorporating such methods. However, low-temperature bleaching methods can generally achieve significant energy savings, as the process requires less energy to heat the bleaching solution to the required temperature. The energy savings can be substantial, with some estimates suggesting that low-temperature bleaching can save more on energy consumption than high-temperature bleaching.

Summary

The low-temperature bleaching brightens and whitens fabrics without causing damage or discolouration. This method offers several advantages over traditional bleaching techniques, including reduced energy consumption, lower environmental impact and improved safety for the fabric and the person handling it. Using low-temperature bleaching can achieve a clean and vibrant appearance of fabrics while minimizing the risk of damage and preserving their quality and lifespan. Overall, low-temperature bleaching is a practical and sustainable solution for enhancing the appearance of textile material.

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