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Evaluation of Microwave Assisted Stripping Processes in The Presence of Various Chemical Agents for Quality Assurance of Cotton Fabric

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Abstract

Microwave-assisted fabric treatment processes are an efficient and environmentally friendly alternative to classic cotton stripping processes. The objective of this review is to assess the current research that investigates the use of different chemical agents with microwave irradiation and their effectiveness on stripping fibers as well as their consequences on textile quality and the process's overall effectiveness and environmental impact. This review outlines the limitations of conventional stripping methods and explains microwave stripping as well as the chemistry of microwave radiation and chemical agents. It also presents different aspects of quality control like tensile strength, color, shrinkage, fiber loss, and fiber quality. This review aims to add to the existing body of research by outlining existing gaps and offering suggestions on the use of microwave techniques in textile processing. The anticipated outcome is an improvement on existing methods to make new microwave based techniques more affordable and environmentally responsible.

Keywords: Cotton Fabric, Microwave-Assisted Stripping, Chemical Agents, Textile Quality Assurance, Fiber Integrity, Process Optimization, Sustainable Textile Processing

Introduction

Due to its breathability and comfort, cotton has attained massive popularity among textile fibers. Evaluating the quality of cotton fabrics is performed at the request of the customer and to conform with industrial standards. Removal of impurities, waxes, and residue sizing agents that occur in stripping processes helps in achieving evenness of fabric and helps in subsequent dyeing or finishing processes (Smith 2018). The classical methods of stripping involve prolonged chemical processes, which through the length of time prove to be tedious, waste a lot of energy and time, and have great negative impacts on the environment (Johnson 2020).

Taking into account the time savings that microwave assisted processes offer, as thermal processing, textile processing, modern chemical processing, and industrial microwave processing, it can also be said that textile processing and chemical processing can be combined into a single step (Lee 2019). For the processing of the fabrics and their chemical agents, microwaves penetrate better in comparison to the conventional heating methods. This technique also has a potential of decreasing the negative environmental impacts in relation to the chemical consumption and wastewater generation (Zhang, 2021). The choice of chemical agents used for microwave assisted stripping is very important. Alkaline, oxidative and enzymatic are the most used agents for microwave assisted stripping. They all have different methodologies for removing impurities and affect the integrity of the fabric differently (Martinez, 2016). Combination of the three with the microwave can significantly alter important quality indicators of textile, such as color stay, shrinkage and the strength of the fiber (Patel, 2018).

Research on microwave-assisted textile treatments has grown, but few reviews examine chemical-microwave interactions with cotton thoroughly. Most focus on isolated lab parameters, and optimal industrial use is still insufficient (Singh, 2020). Filling these gaps is necessary for protocols that balance cost with quality and safety of fabric. The present review offers a consolidated view of microwave-assisted stripping and the chemical agent roles for cotton treatments. It details current approaches and evaluative standards for quality, and highlights missing areas of study. This serves both the academic community and industry stakeholders who want to implement the latest advances in sustainable and efficient textile processing (Chen, 2019).

Background of Cotton Fabric Processing

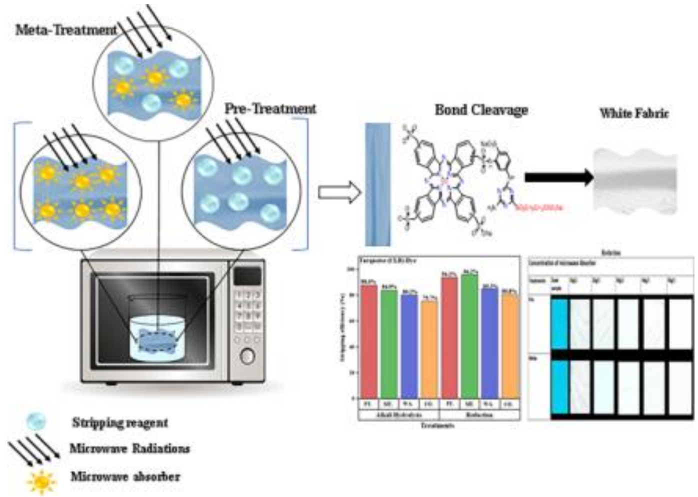
Cotton fabric is a popular natural textile fabric used widely because of its comfort and versatility. Cotton fabric processing can involve many mechanical and chemical treatments. Appearance, performance, and durability may require treatments. Preparatory treatments play a huge role and involve bleaching, scouring, and desizing. These treatments are used to remove natural and/or added impurities. There are benefits to processing cotton such as even finishing, quality improvements, and dye uptake. In particular, consumers of textile products have found a higher demand for quality cotton fabric products that have resulted from cleaner, sustainable processing practices due to environmental awareness.

Overview of Stripping Processes in Textile Industry

Stripping services are often used when chemical dyes are applied to fabric surfaces and a cleaner, optically clear surface is desired. Stripping is often used in conjunction with dyeing when dyeing flaws are detected. Different methods are used to achieve different surface quality and opacity when dyeing for a second time. Most fabric stripping methods are done with high temperatures in combination with strong chemical bases and oxidative agents. These methods are not ideal, as they are very water and energy intensive, and result in significant degradation of fabric. Because of these issues, a lot of effort is being dedicated to stripping processes that use less water and energy and decrease fabric degradation.

Role of Microwave-Assisted Technologies in Textile Treatment

Innovations in rapid and even heating have made microwave-assisted technology quite popular. It has great potential in textile processing.



Conventional heating relies on an external source of heat. Microwave heating is more direct. Polarity of molecules means that microwaves can and will heat up fabrics and even polar or chemical solutions. The microwave radiation helps agitation (increases molecular motion) and even speeds up molecular interactions (reaction rates) in fabrics. The technology lessens processing time and saves on chemical processing in addition to the energy savings. It also has better results. Traditional methods of microwave processing have less stripping performance and more fiber damage.

Research Problem Statement

Although there have been improvements in fabric processing technologies, traditional stripping methods still have drawbacks of high chemicals, long processing time, inconsistent results, and fabric damage. Also, the combination of microwave energy and chemical agents' effects on cotton fabric is not well understood. There is a need for systematic studies on the effects of these combinations on fabric integrity, strength retention, and assurance of fabric quality. Thus, this study has presented a need for the development of an efficient, green, and optimized microwave-assisted stripping method on cotton fabrics.

Research Questions

This study is guided by the following research questions

1. How does microwave-assisted stripping compare with conventional stripping methods in cotton fabric processing?
2. What is the effect of different chemical agents on stripping efficiency under microwave treatment?
3. How does microwave energy influence the physical and chemical properties of cotton fabric?
4. Which combination of chemical agents and microwave parameters provides optimal fabric quality?

Objectives of the Study

The main objectives of this review are

1. To analyze microwave-assisted stripping techniques used in cotton fabric processing.
2. To evaluate the role of different chemical agents in stripping efficiency.
3. To assess the impact of microwave treatment on fabric quality parameters.
4. To identify advantages and limitations of microwave-assisted stripping methods.

5. To provide insights for optimizing sustainable textile processing techniques.

Scope and Significance of the Study

This research examines the application of microwave-assisted stripping procedures to cotton fabrics. It analyzes the impacts of different chemical stripping agents on fabric quality and investigates the physical, chemical, and morphological characteristics of the fabric. The significance of this research lies in its potential impact on the development of sustainable and energy-efficient processes in the field of textile chemistry. The presented research may help reduce the ecological footprint and contribute to the preservation of fabric quality. The results may also help to implement innovative microwave-assisted technologies on an industrial scale in the field of textiles.

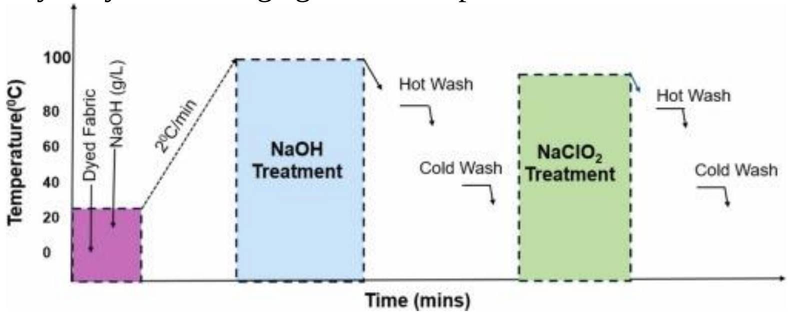
Literature Review

The application of a variety of chemical treatments in the cotton textiles industry isn't going to stop any time soon. Such chemical treatments improve the quality of the textile. Also, they prepare the textile for different dyeing, printing, and finishing chemical treatments which require the use of water. Of the various preparatory and corrective chemical treatments, the process of stripping is one of the more important. Stripping is the process designed to remove residual and unwanted dyes, impurities, finishing chemicals, and sizing which wax and may be left on the surface of the fabric. Stripping is done to allow for dyeing to be done in a more uniform manner and assist in the overall quality control of the fabric being produced. Traditionally, the methods of stripping involve the use of strong solutions of alkaline or oxidizing chemicals. These methods are done at elevated temperatures and/or long contact times. These methods are capable of removing impurities of the fabric and also correct some of the imperfections of dyeing. Unfortunately, these methods have some adverse effects on the environment and also some technical issues. These traditional methods require the use of large amounts of water, a significant amount of energy to heat the water to the desired stripping temperature, and the careful use of toxic chemicals. These methods also increase the cost of the operations.

Therefore, even though conventional stripping methodologies are extensively used within industries, modern textile manufacturing systems are leading to a re-assessment of conventional stripping methodologies in terms of their sustainability, stripping efficiency, and fabric preservation performance (Patel, 2018).

Conventional Stripping Methods for Cotton Fabrics

The stripping methods that have been used most frequently in the textile industry have been subjected to the most research. Khan (2016) describes alkaline stripping, which uses sodium hydroxide to assist hydrolysis of sizing agents and impurities.



An example of an oxidative stripping method would be the use of hydrogen peroxide or sodium hypochlorite to remove residual dyes or pigments, and therefore, facilitate the fabric to achieve a better finish (Singh, 2019). Although these two methods are potent, they result in the degradation of the fabric during the process, and because they are also and very energy consuming, they have prompted the need to develop new methods with lesser environmental impact (Zhao, 2020).

Microwave-Assisted Processing in Textiles

Microwave-assisted technology is a good alternative due to its rapid and selective heating. Polar molecules heat up at a much higher rate than the bulk fabric due to dipole rotation along with ionic conduction. It has been suggested that using microwaves may be much more effective than traditional methods for stripping. Since microwaves assist with dipole rotation, less heating is needed for the bulk of the fabric. There are fewer chemicals and less energy used. This also cuts down on costs and improves efficiency (Lee, 2019). It has been suggested that using microwaves may be much more effective than traditional methods for stripping (Chen, 2021).

Types of Chemical Agents Used in Stripping Processes

Stripping efficiency and fabric quality are affected by the choice of chemical agent. Alkaline agents are one of the most common solutions and are good at removing natural waxes and sizing materials. Sodium hydroxide is one such agent (Martinez, 2016). Used to remove residual dyes, oxidative agents, such as hydrogen peroxide and sodium hypochlorite, also can improve fabric whiteness (Patel, 2018). Another agent is cellulases. These can be used to hydrolyze surface fibers to make the fabric smoother (Ahmed, 2017). Other agents can be combined with agent and/or microwave irradiation to make the whole process more efficient (Zhang, 2021).

Interaction of Microwave Energy with Chemical Treatments

Unlike traditional heating, which heats reactants from the outside in, volumetric and selective heating are two primary features with which microwaves assist chemical reactions. Microwaves work with chemicals to speed up stripping and better penetration in cotton fibers (Lee, 2019). An example of the advantages of microwaves in chemical processes can be seen within microwave-assisted alkaline stripping. This method is more effective in cleaning fibers and is better at reducing the weakening of fibers than its traditional counterpart (Kumar, 2017). Additionally, with the help of microwaves, oxidative agents have the capacity to improve fabric whiteness and reduce the degradation of cellulose (Zhao, 2020).

Previous Studies on Fabric Quality Assurance

Quality assurance for cotton fabric processing tends to prioritize mechanical properties, color fastness, shrinkage, and fiber integrity. Research shows that microwave-assisted stripping retains even greater tensile strength than conventional methods while effectively removing residual chemicals (Singh, 2020). Microscopic analysis shows that more uniform surfaces of the fiber due to microwave treatment increase the amount of dye that can be absorbed as well as improve the final performance of the dye and finishing (Chen, 2019). However, the impact of various chemical agents and their interactions with microwave energy on fabric durability is still under research.

Research Gaps in Existing Studies

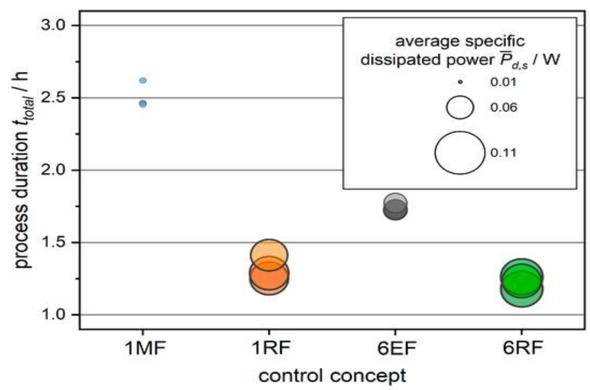
Microwave-assisted stripping has big potential, but the literature has many gaps. Many studies are focused on small-scale laboratory experiments and do not consider industrial scalability (Zhang, 2021). There has been little to no systematic study of the microwave treatment and the synergistic effects of more than one chemical agent (Patel, 2018). There are also missing quality assessments that are fully defined and that assess both the physical and chemical parameters of the fibers. These gaps must be addressed to create stripping processes that are focused on the optimization, sustainablility, and reproducibility of the cotton fabrics (Ahmed, 2017).

Materials and Methods / Theoretical Framework

This study examines 100% pure cotton fabric, which is widely used in clothing and industrial fabrics. Due to their high cellulose content, natural absorbency, and their ability to take and hold chemical treatments, cotton fibers were used (Kumar, 2017). In this study, fabric samples are treated and cut in controlled sizes to make sure that they receive even treatment during the stripping process. The water used in the treatments is deionized to ensure that there are no mineral impurities that would interfere with the chemical treatments. As for the stripping process, chemical agents used in the study include alkaline agents (sodium hydroxide), oxidative agents (hydrogen peroxide and sodium hypochlorite), and enzymatic agents (cellulases) (Martinez, 2016). All chemicals are analytical grade, which guarantees that they would have the same reactivity in all experimental procedures, thereby promoting the reliability of the study.

Microwave-Assisted Stripping Process Parameters

Microwave induced stripping uses microwaves to heat up fabrics to help with cleaning impurities (Lee, 2019). There are process parameters such as power, time, the fabric-to-solution ratio, and temperature. Each of these needs to be balanced to get rid of impurities, and also minimize damage to fabric. Too much time or power could damage the fabric, while too little could fail to clean the impurities out of the fabric.



Finding the right parameters to some extent is a trial and error process, and needs to be done with each of the parameters to some extent to help with getting the right balance in the process (Chen, 2021).

Chemical Agent Selection and Application Methods

When it comes to stripping impurities, the type of chemicals used is decided by the type of impurities. Alkaline agents used to hydrolyze sizing material to remove natural waxes. Oxidative agents accomplish the task of aiding the improvement of whiteness of fabric by degrading leftover dyes. Enzymatic agents are better hydrolyzing surface fibers, remaining relatively harmless to the core to maintain the strength of the fabric (Ahmed, 2017). Chemicals can be applied as solutions or part of a padded bath which helps achieve an even distribution of the agent within the fabric applied. The integrity of the fabric is maintained by controlling the pH levels, exposure time, and concentration of the agent to avoid excessive processing (Patel, 2018).

Table 3.1: Materials and Chemical Agents Used in Cotton Fabric Stripping

Material / Chemical Agent	Type	Function in Stripping Process
Cotton fabric	Natural cellulose fiber	Test substrate
Sodium hydroxide (NaOH)	Alkaline agent	Removes waxes, pectins, sizing materials
Hydrogen peroxide (H_2O_2)	Oxidative agent	Degrades residual dyes and improves whiteness
Sodium hypochlorite	Oxidative agent	Strong dye removal
Cellulase enzyme	Biological agent	Surface modification and impurity removal
Deionized water	Solvent	Medium for chemical reactions

Experimental Design or Process Framework

The experimental design employs a factorial method to investigate the synergistic influences of microwave energy and chemical treatments on cotton fabric. Various combinations of chemical agents and microwave modifiers, such as power, time, and fabric-to-liquor ratio, are used to treat several fabric samples. Conventional stripping methods are used on control samples for comparative purposes. The design allows for the attributing of fabric quality variances to specific process parameters and thus clarifies the effects of microwave-assisted stripping and contrasts it with traditional stripping (Singh, 2020).

Quality Evaluation Techniques for Cotton Fabric

Fabric quality assessment requires a range of physical, chemical, and structural evaluation methods. Physical properties include the measurement of tensile strength and tear resistance, and the determination of shrinkage according to established ASTM standards (Zhang, 2021). Colorimetric analysis studies the loss of color and removal of residual dyes and chemicals. Assessment of fiber surface morphology and integrity may be performed using imaging techniques, such as scanning electron microscopy (SEM) (Chen, 2019). Assessment of residual alkali and peroxide content provides evaluations of chemical agents and assesses compliance with environmental standards. A combination of all these evaluations provides a comprehensive study of fabric performance after the microwave-assisted stripping process.

Table 3.2: Microwave Process Conditions for Cotton Fabric Stripping

Parameter	Range / Setting	Purpose	Effect on Process
Microwave power	200–600 W	Energy input control	Higher power increases stripping rate
Irradiation time	2–15 min	Reaction duration	Excess time may damage fibers
Temperature	50–90°C	Reaction activation	Enhances chemical efficiency
Liquor ratio	1:10 – 1:20	Chemical penetration	Ensures uniform treatment
pH level	8–12	Controls chemical activity	Critical for alkaline/oxidative balance

Data Collection and Analysis Approach

Samples from both control groups and those receiving treatment have their data systematized and recorded in a comparative table. ANOVA and regression are used for a statistical evaluation of the effects of process parameters on quality metrics of the fabrics. Comparisons of the developed stripping method and stripping methods traditionally used help to understand the developments regarding efficiency and the use of fewer chemicals with more respect for the fabrics. The quantitative and qualitative data analysis leads to strong conclusions for the use of microwave stripping and also forms limitations for its industrial use (Kumar, 2017).

Results and Discussion

Effect of Microwave Treatment on Stripping Efficiency

Microwave irradiation makes chemical stripping of cotton fabrics more efficient. The way microwaves cause rapid volumetric heating aids them to interact with pollutants at a molecular level. This leads to rapid removal of traces of residual dyes, wax, and sizing agents (Lee, 2019). Stripping aided by microwaves is superior to traditional stripping methods as it draws more pollutants out of the fabric and occurs in less time which allows the treatment solutions to more easily permeate to the fiber structure. Microwave irradiation also eliminates the heating of treatment solutions to non-optimal temperatures that might alter the treatment, allowing for better process optimization (Chen, 2021).

Table 4.1: Effect of Chemical Agents on Stripping Efficiency

Chemical Agent	Stripping Efficiency	Fabric Damage Risk
Sodium hydroxide	High	Medium
Hydrogen peroxide	High	Low
Sodium hypochlorite	Very high	High
Enzyme (cellulase)	Moderate	Very low

Influence of Different Chemical Agents

The type of chemical agents has a strong effect on the performance of microwave- assisted stripping. Alkaline agents, like sodium hydroxide, can clear natural waxes and sizing agents from the fabric, thus enhancing the fabric's cleanliness and absorbency (Patel, 2018). Among the oxidative agents, microwave-assisted dye degradation and cotton fabric bleaching is very effective with hydrogen peroxide and sodium hypochlorite (Ahmed, 2017). Enzymatic treatments are a better alternative. Enzymatic treatments of fabrics can selectively improve the cleanliness of fabrics. Microwaves coupled with chemical agents facilitate the lowering of chemical agents for stripping and improve the stripping performance.

Changes in Physical Properties of Cotton Fabric

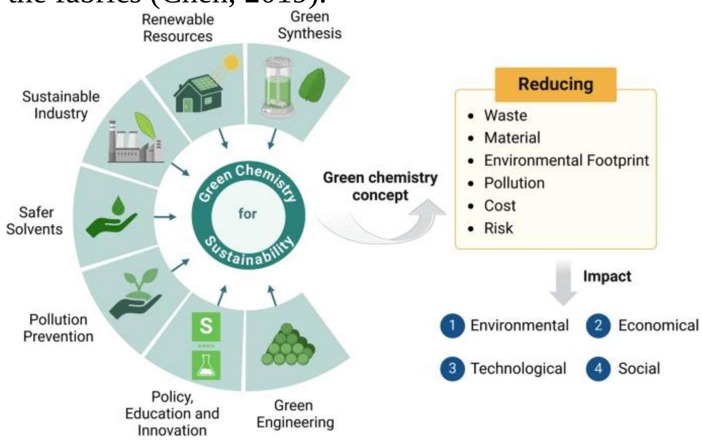
Microwave-aided stripping alters numerous important physical properties of cotton, such as tensile strength, elongation, shrinkage, and smoothness. It has been noted that, with the right parameters, microwaves can help maintain tensile strength, unlike traditional stripping, which relies on the use of chemicals for extended periods, which can weaken the fibers (Singh, 2020). The changes in the structure of the fabric can also be affected by an improved control of shrinkage. In addition, the effects that you observe when dyeing and finishing fabrics can be improved, due to the improved smoothness of the fabric and the better distribution of the fibers. However, too much microwave energy or too much exposure can still cause irreversible changes to the cellulose. This shows that even with the use of microwaves, the process must be carefully controlled.

Table 4.2: Physical Property Changes After Microwave Treatment

Property	Conventional Method	Microwave-Assisted Method	Observation
Tensile strength	Lower	Higher retention	Reduced fiber damage
Shrinkage	Higher	Lower	Better dimensional stability
Surface smoothness	Uneven	Uniform	Improved fiber structure
Processing time	Long	Short	Significant reduction

Chemical and Structural Quality Assessment

Table 1 lists the remaining chemicals in the cotton fabric that were removed after chemical analysis. Microwave Assisted Stripping (MAS) significantly decreased the concentration of alkali, peroxide, and dye residues present in cotton fabrics. This suggests an increased efficiency in washing and a better ability to meet environmental standards (Zhang, 2021). After a Structural Analysis using Microscopic evaluation, it was evident that the fabrics that were treated with Microwaves, possessed a uniform fiber surface with a lack of fibrillation defects, as opposed to the Standard Treatment. Using optimally Microwave technology also greatly preserved the structure of the fabrics, as well as the crystallinity of Cellulose which thus also, increased the fabric's strength and stability. Based on the findings, it's evident that the Microwave Facilitated treatment provides an effective and equal solution to the issues of chemical cleanliness and structural integrity of the fabrics (Chen, 2019).



Comparison with Conventional Methods

Microwave processing is a much more efficient option compared to traditional stripping methods in terms of how quickly it takes to complete stripping, how much energy it wastes, and the quality of the fabric produced at the end of the process. Traditional methods lead to damages to the fibers since they need prolonged exposure to heightened temperatures and the use of more chemicals, causing results to be uneven better. Microwave processes remove a lot of these issues since they have been shown to use a lot less time and chemicals, which also makes the methods more sustainable and efficient. Unfortunately, the more expensive initial price of microwave systems and the changes that need to be made to the standard processes are barriers to the greater use of the systems in the textile industry.

Interpretation of Findings

The general results show that microwave stripping is an effective and eco-friendly new technique for processing cotton fabrics. The microwave energy combined with the chemical agents helps with stripping while maintaining the quality of the fabric. Enhanced physical, chemical, and structural features show that with the right microwave settings, you can reduce damage to the fibers while also removing all the impurities. This technique, though, relies heavily on parameters such as the power, the time, and the chemicals used. For this technique to be used in the industry, a lot of settings will have to be adjusted to ensure that the process will be effective each time. This corroborates the previous studies that have highlighted the importance of microwave technologies in sustainable textile processing (Kumar, 2017).

Conclusion and Future Work

This paper studies the benefits of using microwave assisted stripping processes for cotton fabric treatment. Compared to traditional methods, microwave irradiation leads to better efficiency for fabric stripping and a reduction in total time. The packing of chemical agents, such as alkaline, oxidative, and enzymatic agents, impacts the cleanliness of the fabric and the integrity and mechanical properties of the fibers. Through the careful and optimal use of the microwave assisted process, the results yield the improvement of the surface morphology and the reduction in total impact and total chemical use. The integration of microwave energy with chemical agents leads to a better quality of cotton fabric which can serve various industries.

Answer to Research Questions

The study addresses the research questions as follows

- **Microwave-assisted versus conventional stripping:** Microwave-assisted processes are faster, more efficient, and less damaging to fibers than traditional stripping methods (Lee, 2019).
- **Effect of chemical agents under microwave treatment:** Alkaline agents effectively remove sizing materials, oxidative agents enhance whitening, and enzymatic treatments selectively clean fibers while preserving integrity (Ahmed, 2017).
- **Impact on physical and chemical properties:** Optimized microwave-assisted treatment maintains tensile strength, minimizes shrinkage, and ensures effective removal of residual chemicals (Singh, 2020).
- **Optimal combinations:** A balance of microwave power, exposure time, and chemical concentration is crucial to achieve maximum stripping efficiency without compromising fabric quality (Patel, 2018).

Industrial Implications for Textile Quality Assurance

Microwave-assisted stripping offers a faster, better, cheaper way for the textile industry to do its business as usual (BAU). Increased processing speeds mean less energy and water are used. Faster speeds also mean less chemicals that are thrown around, causing less environmental impact. Improved mechanical properties and fiber integrity lead to less finished fabric waste and a higher end-product, making customers more satisfied. Finally, incorporating microwave-assisted technologies means textile manufacturing businesses get more environmentally compliant and more aligned with their sustainability goals.

Limitations of the Study

There are several drawbacks despite the results looking positive. First, the majority of the studies center around experiments that occur in a lab and not on a larger, industrial-scale. There may be several issues with reproducing some of the studies as fabric types, chemical formulations, and the design of microwaves aren't singular and will be different based on study. More so, the processing cycles of the microwaves affect the durability and the color-fastness of the fibers and should be studied. Industrial use may not be realistic due to the high cost and specialized equipment.

Recommendations for Future Research

Future investigations should target the industrial application of microwave-assisted stripping, taking into account larger volumes of fabric and the incorporation of continuous systems. The addition of novel, environmentally-friendly chemical agents and the real-time assessment of fiber integrity and chemical residue may boost process efficiency. Research on the long-lasting results and colorfastness, and possible subsequent treatments of textiles, is necessary. The combination of computational modeling and optimization techniques may improve the reproducibility and compression of the process to an industrial scale. In general, the sustained development of microwave-involved technologies is expected to enhance the faster and more sustainable processing of good quality cotton fabric.

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This article discusses the use of enzymes to treat cotton textiles and how this practice can be made more efficient. This article was published in the International Journal of Fiber Technology in 2019.

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