

Application and Prospect of Ecological Dyeing Technology in Clothing Manufacturing

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ABSTRACT

In recent years, many factories that produce synthetic dyes for the textile industry have been closed due to environmental inspections. After these closures, new dyeing methods for textiles are emerging. With the progress of society and the improvement of people's quality of life, people pay more and more attention to the environment and their own health level. Wearing "green textiles" and "ecological textiles" has become a life demand of people today. Developing clean production in the textile industry, using green production methods that are conducive to protecting the ecological environment, and providing consumers with ecological textiles are global themes for the world textile industry entering the 21st century, and are important contents related to the quality of human survival and sustainable development. Ecological dyeing technology is the key development direction of textile fabric dyeing in the future. This article focuses on the application and prospects of ecological dyeing technology in clothing manufacturing. In the face of the current severe situation in the textile industry, it is necessary to vigorously develop natural ecological functional textiles. Huge market opportunities are already in front of us. Natural ecological functional textiles will surely become a new force in the textile and garment industry, and the market prospects are bright.

Keywords— clothing manufacturing, ecological dyeing technology, clothing industry, dyeing process technology

INTRODUCTION

Entering the 21st century, with the global call for "ecology, green, and environmental protection", ecological dyeing technology has once again attracted worldwide attention due to its non-toxic, harmless, environmentally friendly, and biodegradable properties. In addition, the exhaust gas generated by the burning of materials such as candles used in the batik process may also pollute the air. Ecological dyeing technology uses environmentally friendly fiber materials, dyes and chemicals to ensure that the dyeing process is safe and ecological, without destroying resources or polluting the environment. It helps to reduce resource consumption and reduce environmental pollution, which is in line with the core concept of sustainable development. At the same time, the application of ecological dyeing technology has also promoted the increase in demand for environmentally friendly materials in the clothing industry and promoted the balanced development of the industrial ecosystem. Therefore, ecological dyeing technology is a key link in achieving sustainable development of clothing manufacturing, which is of great significance to the long-term development of the industry and the improvement of the earth's environment. Exploring ecological dyeing technology in clothing manufacturing aims to reduce environmental pollution, improve resource utilization efficiency, and protect human health. This technology strives to use environmentally friendly dyes and energy-saving processes, reduce wastewater discharge and harmful substance residues, achieve sustainable development, inject green power into the fashion industry, and promote harmonious coexistence between man and nature. This paper elaborates on the literature review, the definition, technology and advantages of ecological dyeing technology, the application of ecological dyeing technology in clothing manufacturing, the impact of ecological dyeing technology on the environment and economy, and the prospects and future directions.

LITERATURE REVIEW

Common traditional dyeing methods include hank dyeing, package dyeing and garment dyeing. Although hank dyeing has good effects, it is time-consuming; package dyeing has high efficiency, but the fluffiness and softness are not good; garment dyeing directly dyes the clothes and is easy to operate [1]. However, these traditional dyeing methods also have obvious disadvantages, such as the difference between the inner and outer layers, insufficient color fastness, and low output. As consumers pay more attention to ecological and environmental protection, ecological dyeing technology has become an important development direction for the textile industry. It can not only reduce resource consumption and environmental pollution, but also improve the safety and health of products. In the future, with the advancement of science and technology and the improvement of consumer demand, ecological dyeing technology will continue to be optimized and promoted, injecting new impetus into the sustainable development of the textile industry. The dyes used in ecological dyeing must meet ecological requirements. The first choice is pure natural plant dyes. This type of dye comes from nature, is degradable, non-toxic, and will not cause harm to the human body and the environment. The second is biological dyes, which are also natural products and have similar effects to plant dyes. Since natural pigments, especially biological pigments, have evolved from organisms on Earth over a long period of time, they maintain ecological balance and have little or no harm to organisms. The third is improved artificial synthetic dyes. Due to the improvement of this type of dye, some substances that do not meet the environmental protection requirements have been removed or reduced to a minimum [2]. At present, there is still a certain degree of difficulty in fully meeting the requirements of ecological dyeing. However, with the focus of active dye research shifting to eco-friendly and the development of some new environmentally friendly products in recent years, a lot of progress has been made in the selection of raw materials for ecological dyeing. In addition, while developing and improving active dyes, the industry is also continuing to study active dye dyeing technology. Many new dyeing auxiliaries have been developed, and many efficient and environmentally friendly dyeing processes have also made great progress.

Ecological Dyeing Technology

Definition and Classification

Dyeing processing is based on a safer and more complete production and processing chain. The fiber materials, dyes and chemicals are environmentally friendly and have no harmful effects on the human body and the environment. The production and processing process is safe and ecological, and will not damage resources or pollute the environment. It is efficient and highly automated. The products are safe, healthy and multifunctional, and the entire production chain is strictly monitored. In order to establish a clean dyeing processing chain, it is necessary to work together from the entire process of raw materials, product design, processing and application to establish a clean dyeing production system [3]. In addition, the products of ecological dyeing are safe, healthy and multifunctional, and the entire production chain is strictly monitored. Ecological dyeing technology can currently be divided into the following categories:

Pure natural plant dyeing. Using pure natural plant dyes, biological dyes and some natural mineral dyes, no chemical synthetic auxiliaries are used in the dyeing process. It is the safest and most environmentally friendly dyeing process, especially for the dyeing of ecological fibers such as organic cotton, which has excellent effects and ensures the organic nature of textiles.

Bionic dyeing. Imitating the structure, distribution and function of pigments in organisms for bionic dyeing is a new ecological dyeing method.

Supercritical carbon dioxide fluid dyeing (SFD). This is a non-aqueous dyeing method. Supercritical carbon dioxide fluid dyeing is suitable for chemical fibers such as polyester, nylon, spandex and acetate fibers. The loss rate during the dyeing process is only 2% to 5%, which has the advantages of no pollution and low energy consumption.

Short process dyeing. Short process dyeing technology greatly improves production efficiency, reduces technical processes, greatly improves product quality stability, and reduces dyeing costs.

Electrochemical dyeing. This is a new dyeing method, which uses electrochemical cathode reduction instead of the electrolytic powder reduction dyeing process. It can not only maintain the advantages of reduction dyes, but also the dye liquor can be reused, saving 80% of chemical reagents and a large amount of water, reducing dyeing costs, and greatly reducing the sewage treatment costs of dyeing plants.

Reactive dyeing. Although many environmentally friendly products have been developed for reactive dyes, the utilization rate of dyes is low. Reactive dyes have low directness to cellulose fibers, and hydrolysis will occur during dyeing, with a loss rate of 50%.

Low-salt dyeing. In order to solve the problem of electrolyte pollution caused by the addition of a large amount of medium-sized electrolytes during the soaking of reactive dyes, low-salt reactive dyes and dyeing processes have been developed at home and abroad.

Deep and thick color dyeing. Reactive dyes are dyeing more and more dark colors, especially navy blue and black. In order to reduce dyeing pollution, it can be controlled by deep and thick color dyeing.

Fast dyeing. Methods to increase color fastness include selecting reactive dyes with good fastness; modifying the fibers, such as physically or chemically modifying them, increasing the degree of dye reaction, introducing dye-protective components into the fibers, etc.; selecting appropriate fixing agents or cross-linking agents for treatment, etc.

Commonly Used Ecological Dyeing Techniques

Commonly used ecological dyeing technologies are mainly the following: First, low-salt dyeing method. Low-salt dyeing method is an environmentally friendly and efficient dyeing technology that aims to reduce the use of inorganic salts in the dyeing process to reduce dyeing costs and reduce environmental pollution. The research and application of low-salt dyeing method mainly targets the dyeing process of cotton fabrics. By adopting different methods and techniques, the use of inorganic salts can be reduced while maintaining or improving the dyeing rate and dyeing quality of the dye.

Second, plant dyes. People have realized that many textiles processed with synthetic dyes have caused serious damage to human health and the human living environment. Therefore, natural plant dyes have been favored by people again. Plant dyes have the following advantages: Plant dyes come from the plant world and are renewable; Plant dyes are directly taken from Chinese herbal medicines without adding any harmful chemicals; The production process of plant dyes is essentially a pigment extraction process, and its residue can be used as high-quality fertilizer after certain treatment. Because plant dyes are non-toxic, harmless, and pollution-free, they have good biodegradability and good compatibility with the environment [4]. Therefore, plant dyes with natural color, natural fragrance and health care functions have incomparable advantages over synthetic dyes.

Advantages of Eco-dyeing Technology

From the perspective of environmental benefits, eco-dyeing technology reduces the use of chemical dyes and reduces the discharge of wastewater and exhaust gas, thereby effectively protecting water resources and the atmospheric environment. From the perspective of economic benefits, although the initial investment in eco-dyeing may be high, in the long run, cost savings can be achieved due to the improvement of resource utilization and the reduction of pollution control costs. From the perspective of social benefits, it has improved the public's awareness and participation in environmental protection and promoted the formation of green production and consumption patterns.

APPLICATION OF ECOLOGICAL DYEING TECHNOLOGY IN CLOTHING MANUFACTURING

Case Study

Suppliers to the textile industry are looking at how to change processes that result in high concentrations of dyes and chemicals such as chromium, arsenic, copper and zinc in wastewater. Now, research and development (R&D) is increasingly focused on new sustainable products and processes that can ensure that recommended products meet legal, voluntary and brand and retailer restricted substances lists (RSL) requirements. The biggest challenge is cost. Price competition is fierce, and profits are shrinking due to fluctuating raw material costs and rising wages. Despite public commitments from clothing brands to become more sustainable, suppliers say their customers won't buy anything that might increase the cost of finished clothing by a penny [5].

Here are examples of successful implementations of eco-dyeing technology:

Cotton requires more water to dye than other textiles, with about 200 liters of water required to produce 1 kilogram of fabric. Dow has developed a pre-treatment process called ECOFAST Pure, which is used to produce cationic cotton before the dyeing process. The pre-treated cotton acquires a permanent positive charge, giving it a higher affinity for negatively charged molecules such as dyes. This patented technology reduces the use of dyes and water for dyeing cotton by 50%. Color-Zen has innovated a technology that pre-treats raw cotton fibers using a wetting agent, caustic soda, and ammonium salt solution. This pre-treated cotton has an enhanced ability to hold dyes without the need for fixing chemicals, thereby reducing the use of toxic chemicals by 95% and water waste by 90%. Color-Zen has developed a cotton pre-treatment step that allows raw cotton fibers to be treated directly from the field. The company's technical director said the process speeds up the dyeing process while reducing water by 90%, energy by 75%, and auxiliary chemicals by 90%. It also reduces the amount of dye by almost half compared to processes that require adding salt to the dye bath.

Pre-reduced indigo liquor can produce cleaner denim and has a huge positive impact on resource efficiency, such as significantly reduced use of sodium bisulfite, cleaner wastewater and less water usage. In addition, the rapid and reliable online determination of important dyebath parameters such as indigo concentration, reducing agent concentration, pH, redox potential, temperature and electrolyte concentration can help optimize the dyeing process and save precious resources. "Synthetic indigo used to make blue jeans is a dye that can release unreacted chemicals downstream in the manufacturing process. In response, color chemistry company Archroma has developed a technology to pre-reduced indigo to prevent the chemical aniline from passing through as a contaminant. Eco-foot has developed a hybrid pigment consisting of a dye chemically linked to a polymer particle that reacts with cellulosic fibers at temperatures as low as 25°C. This technology does not require the use of salts, which are otherwise essential to infuse the dye into the fabric. This technology can be used to dye cotton garments at low temperatures and can also be used for more environmentally friendly wool dyeing. Eco-Indigo is a hybrid pigment for denim dyeing that avoids the use of water-soluble indigo pigments that are traditionally used to convert indigo pigments into a water-soluble form. Toxic reducing agents. Common reducing agents are considered environmentally unfriendly because of the sulfites and sulfates produced in the dye baths that are discharged into the wastewater causing various problems.

Eco-foot has also developed auxiliaries to prevent dyes from hydrolyzing during the dyeing process, which usually requires harsh washing procedures to remove the hydrolyzed dyes. Together with mixing pigments and auxiliaries, more than 50% of water can be saved in intermediate rinses and final rinses throughout the preparation and dyeing process.

In addition to these dyeing methods, other solutions are also emerging. Even the best pre-treatment processes cannot eliminate the health effects of dyes and the chemicals used to make dyes. This is the focus of many eco-certification programs in the textile industry. Oeko-Tex's non-toxic textile certification currently covers more than 300 chemicals, compared to just 100 initially.

Challenges and Solutions

The main challenges faced by ecological dyeing technology in the application process are technical maturity and economic cost. In terms of technology, although ecological dyeing technology helps to reduce environmental pollution, its dyeing effect is still somewhat different from that of traditional technology, and there are also problems with dye stability and dyeing efficiency. In terms of economy, the cost of ecological dyeing technology is relatively high, including dye cost, process control cost and equipment update cost, which makes many companies reluctant to adopt it. There are also some potential solutions to these challenges. In terms of technology, researchers need to continue to work on improving the stability and dyeing efficiency of ecological dyes, while exploring more types of ecological dyes to enrich the dyeing effect [6]. In terms of economy, the government and enterprises need to jointly promote the research and development and application of ecological dyeing technology, and reduce the application cost of enterprises through policy support and financial subsidies.

In addition, an industrial chain of ecological dyeing technology can be established to achieve the integration and optimization of dyes, equipment and processes, and further reduce costs. In general, although ecological dyeing technology faces challenges, with the continuous advancement of technology and the continuous promotion of application, it is believed that these challenges will gradually be overcome, and ecological dyeing technology will be more widely used in the future.

Comparative Analysis

In the field of clothing manufacturing, ecological dyeing technology shows significant advantages in performance and results compared to traditional methods. Traditional dyeing methods often use harmful chemicals, which not only pollutes the environment but may also affect the health of workers. Ecological dyeing technology uses environmentally friendly dyes and auxiliaries, which significantly reduces the emission of harmful substances and is more in line with the concept of sustainable development.

In terms of performance, ecological dyeing technology has higher color fastness and more uniform coloring effects [7]. Its unique dyeing process ensures better penetration of dye into the fiber and improves color durability. At the same time, ecological dyeing technology can also effectively reduce wastewater production, reduce energy consumption, and improve production efficiency. Judging from the results, clothing using ecological dyeing technology is superior to traditional methods in terms of color vividness, fullness and color fastness. In addition, ecological dyeing technology can also give clothing better softness and breathability, improving wearing comfort.

The impact of ecological dyeing on the environment and economy

Environmental Sustainability

Ecological dyeing, as a dyeing technology that pays attention to environmental protection, has a significant impact on reducing pollution and saving resources. In terms of reducing pollution, ecological dyeing technology greatly reduces the emission of harmful substances by using environmentally friendly dyes and chemicals. Compared with chemical dyes commonly used in traditional dyeing processes, ecological dyes do not contain harmful ingredients and will not cause long-term pollution to the environment [8].

In addition, ecological dyeing technology also optimizes wastewater treatment during the dyeing process, achieving recycling and standard discharge of wastewater, effectively reducing pollution of water resources. In terms of saving resources, ecological dyeing technology also shows its advantages. By improving dyeing processes and equipment, ecological dyeing improves dye utilization and reduces dye waste. At the same time, recycling dyeing wastewater also reduces water consumption. These measures not only help save resources, but also reduce production costs and improve the economic benefits of the enterprise.

Economic Feasibility

The cost of ecological dyeing technology is relatively high. This stems primarily from the cost of the eco-dyes themselves and the special equipment and process controls required to apply the technology. Ecological dyes usually use natural ingredients, and their extraction and processing processes are complicated, resulting in higher prices than traditional chemical dyes. In addition, in order to ensure the dyeing effect and quality, ecological dyeing technology also requires stricter dyeing conditions and finer process control, which further increases the cost [9]. Therefore, for clothing manufacturers, adopting ecological dyeing technology means investing more money in purchasing dyes and equipment, as well as training employees in new dyeing techniques. These additional investments undoubtedly increase production costs and may lead to an increase in product prices. However, from a market competitiveness perspective, adopting ecological dyeing technology also brings significant advantages. As consumers' attention to environmental protection and health issues continues to increase, more and more consumers tend to purchase environmentally friendly and healthy products [10].

Therefore, clothing manufacturers that adopt ecological dyeing technology can take this opportunity to shape their brand image and enhance the market competitiveness of their products. In addition, some countries and regions have begun to implement strict environmental regulations, restricting or penalizing manufacturers who use traditional chemical dyes. Therefore, adopting eco-dyeing technology also helps manufacturers comply with regulations and avoid potential legal risks.

Social Impact

With the increasing awareness of environmental protection, more and more consumers are beginning to pay attention to the environmental attributes of products. As an environmentally friendly dyeing method, ecological dyeing has been favored by consumers for its environmental friendliness and harmlessness to the human body [11]. Ecological dyeing uses environmentally friendly dyes and chemicals, does not contain toxic and hazardous substances, and is safe and harmless to the environment and human body. This dyeing method not only reduces the risk of air and water pollution, but also helps to protect ecosystems and biodiversity. For consumers, choosing ecologically dyed products means contributing to environmental protection while also reducing their own health risks.

In addition, the benefits of reducing the use of chemicals on health are obvious. Many chemicals are irritating or toxic to organs such as the skin and respiratory tract, and long-term exposure may lead to various health problems. Reducing the use of chemicals can reduce these risks and protect our physical health [12]. At the same time, reducing the use of chemicals can also help reduce environmental pollution and protect our common home, the Earth.

PROSPECTS AND FUTURE DIRECTIONS

Application Prospects

At present, the natural dyes used for ecological dyeing have soft colors and natural characteristics. Environmentally friendly fabrics dyed with natural dyes are very popular in the domestic and foreign markets. For example, the high-count Tiansuli "green" environmentally friendly high-end fabrics made of plant dyes not only meet the requirements of high-count, light and thin, and diversified functions of fine wool at home and abroad, but also meet the requirements of environmentally friendly natural fabrics currently advocated internationally. Natural dyes can not only dye protein fiber fabrics such as silk and wool, but also dye cellulose fiber fabrics such as cotton and linen, and can also dye synthetic fiber fabrics such as acrylic, polyester, and nylon. Therefore, natural dyes used for ecological dyeing have good application prospects.

High-end silk products

Because silk is comfortable to wear, in addition to being used as high-end dresses, most of it is used for underwear, pajamas and other close-fitting clothing, but this also places higher requirements on the environmental protection ecology of dyeing and finishing. There are originally few varieties of synthetic dyes used for dyeing silk, and now many of them are banned for environmental reasons, which makes silk dyeing a problem. Most varieties of natural dyes can be used for silk dyeing, which has been tested by long-term practice.

Health underwear and children's clothing

Nowadays, green textiles that are comfortable and healthy for the human body will become the most basic content of family health consumption. Most underwear, pajamas and other close-fitting clothing, as well as children's clothing, have higher requirements for environmental protection and ecology in dyeing and finishing. Infants and young children are the most vulnerable group. The use of plant dyes in infant clothing and supplies is likely to be popular in the market and has a high development prospect. Baby clothes, children's blankets, children's socks, bedding, etc. have excellent prospects for use and are quickly accepted by the market, so textiles dyed with natural dyes will become the new force in health underwear and children's clothing.

Market Trends

With the development of modern economy, science and technology, and the progress of social civilization, people are paying more and more attention to their personal living environment, working environment, health and life span. In order to adapt to and improve people's living and working environment, improve people's quality of life and life quality, and expand human activity space, natural ecological fabrics have occupied an increasingly large proportion in people's popular life. Out of consideration for ecological environmental protection, more and more consumers have begun to pay attention to and buy ecological underwear, ecological children's clothing, ecological home textiles, ecological toys, etc.

In addition, technological progress has also made it possible to adopt ecological dyeing technology. With the development of science and technology, more and more new technologies have been applied to the field of dyeing, which has improved the efficiency and quality of ecological dyeing technology, and further promoted its popularization and application in the market.

CONCLUSIONS

As consumers pay more and more attention to health and environmental awareness, clothing and home brands also list these two points as important indicators. Ecological dyeing technology also meets the market's demand for green, healthy and sustainable products. Looking to the future, the research field of ecological dyeing technology will be more extensive. Dyeing is a key process to make fabrics or fiber yarns present rich colors, and it is an indispensable part of textile manufacturing. It not only gives textiles a unique appearance and texture, but also is an important means to enhance their added value and market competitiveness. With the continuous advancement of science and technology, dyeing technology is also constantly developing and innovating. From the adoption of natural dyes to the invention of synthetic dyes, from traditional manual dyeing to modern automated dyeing, each innovation has brought great changes to the textile industry.

In summary, in the future, dyeing processing will be based on a safer and more complete production and processing chain. Fiber materials, dyes and chemicals are environmentally friendly and have no harmful effects on the human body and the environment. In terms of materials, we can try to explore more natural and renewable dye materials. In terms of technology, we can also optimize the dyeing process to improve dyeing efficiency and product quality. In addition, the integration and innovation of eco-dyeing technology with other technologies, such as nanotechnology and digital technology, will also become a research hotspot, jointly promoting the progress of sustainable clothing manufacturing.

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