THEORETICAL FOUNDATIONS AND MODERN APPROACHES TO TEXTILE WASTE RECYCLING: A REVIEW OF RESOURCE-EFFICIENT TECHNOLOGIES

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Abstract The increasing volume of textile waste generated by textile manufacturing and consumer activities has become a significant environmental and economic challenge worldwide. The textile industry produces substantial amounts of cotton, wool, synthetic, and blended fiber waste during spinning, weaving, knitting, dyeing, and garment manufacturing processes. This study reviews the theoretical foundations of textile waste recycling and evaluates modern resource-efficient technologies for waste utilization. The classification, characteristics, and recycling potential of textile waste are analyzed based on scientific literature and industrial practices. Particular attention is given to cotton and wool waste processing technologies, including mechanical fiber regeneration, ultrasonic cleaning, hydrodynamic washing, thermal-moisture treatment, and advanced impurity removal systems. The analysis demonstrates that textile waste contains a considerable proportion of recoverable fibers suitable for producing yarns, nonwoven materials, insulation products, and technical textiles. The findings indicate that improved recycling technologies can significantly reduce environmental impacts, decrease raw material consumption, and enhance the sustainability of textile production systems.

Keywords: Textile waste, fiber regeneration, cotton waste, wool waste, recycling technologies, circular economy, sustainability, nonwoven materials.

1. Introduction

The textile industry is one of the most important manufacturing sectors worldwide and plays a significant role in economic development. However, the industry generates considerable quantities of waste throughout the production chain. According to recent studies, textile waste constitutes a growing proportion of industrial and municipal solid waste streams. The continuous increase in textile consumption and production has intensified concerns regarding resource depletion, environmental pollution, and waste management.

The concept of a circular economy has encouraged the development of technologies aimed at recovering valuable materials from textile waste. Recycling not only reduces environmental burdens but also contributes to resource conservation and economic efficiency. Textile waste recycling is particularly important because raw materials account for a major proportion of textile production costs.

Numerous researchers have investigated waste recovery technologies, fiber regeneration processes, and equipment improvements aimed at increasing recycling efficiency. Nevertheless, significant challenges remain regarding fiber quality preservation, impurity removal, and energy consumption.

The purpose of this review is to analyze the theoretical basis of textile waste recycling and assess modern technological approaches for recovering valuable fibers from textile waste.

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2. Classification of Textile Waste

Textile waste can be classified according to its origin, composition, and recycling potential. Industrial textile waste is generated during manufacturing

operations and includes:

opening and cleaning waste;

carding waste;

combing noils;

spinning waste;

yarn breakages;

weaving waste;

fabric cutting scraps;

finishing waste. Industrial waste generally contains relatively clean fibers and therefore has high recycling potential. Post-consumer textile waste consists of used textile products that have reached the end of their service life. These include:

clothing;

household textiles;

carpets;

upholstery materials;

technical textiles. Unlike industrial waste, post-consumer waste requires sorting, cleaning, and additional preparation before recycling. Based on fiber composition, textile waste can be categorized as:

cotton waste;

wool waste;

flax waste;

synthetic fiber waste;

regenerated fiber waste;

blended textile waste. Each category requires specific processing technologies due to differences in fiber structure and physical properties

3. Characteristics of Cotton Textile Waste

Cotton remains one of the most widely used natural fibers in the textile industry. During processing, a significant amount of waste is generated. Research indicates that cotton-processing enterprises produce between 7% and 30% waste depending on equipment conditions and technological parameters. Major cotton

waste fractions include:

carding droppings;

pneumatic cleaning waste;

fly waste;

spinning waste;

yarn remnants.

Cotton waste contains:

usable fibers;

short fibers;

seed coat fragments;

dust particles;

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plant impurities.

Studies have shown that waste fibers often retain sufficient length and strength for secondary utilization. After cleaning and regeneration, many waste fractions can be successfully incorporated into medium-count yarns and nonwoven products.

4. Characteristics of Wool Textile Waste

Wool processing generates waste at nearly every stage of production.

The main wool waste streams include:

raw wool cleaning waste;

carding waste;

spinning waste;

weaving waste;

knitting waste;

finishing waste.

Raw wool impurities typically include:

vegetable matter;

mineral contaminants;

grease;

sweat residues;

dust.

Experimental studies indicate that vegetable contamination may vary from 0.5% to 22%, while grease content may reach 30%. Wool waste possesses significant recycling potential because keratin fibers maintain valuable thermal and acoustic insulation properties even after regeneration.

5. Modern Technologies for Textile Waste Recycling

Mechanical recycling remains the most widely applied textile waste recovery technology.

The process includes:

opening;

cleaning;

blending;

carding;

fiber regeneration.

Mechanical recycling offers low operational costs but may reduce fiber length and strength.

Kostylev proposed ultrasonic wool cleaning technology aimed at improving contaminant removal efficiency.

The technology provides several advantages:

improved removal of mineral impurities;

enhanced grease extraction;

reduced detergent consumption;

lower environmental impact. Experimental results demonstrated a reduction in surfactant consumption of approximately 28%. Pichnikova investigated hydrodynamic interactions during wool washing processes. Improved washing systems incorporating freely rotating hollow cylinders achieved:

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enhanced impurity removal;

improved washing uniformity;

reduced fiber damage.

These developments contribute to higher-quality regenerated fibers.

Shvidkiy developed thermal-moisture treatment methods for textile waste regeneration.

This approach:

softens fibers before opening;

reduces fiber breakage;

preserves fiber length;

improves mechanical properties.

The technology has demonstrated promising results for wool and blended textile waste recovery.

Recent studies conducted by Haydarov, Nizomov, and Dadaboyev have focused on improving cleaning machine designs.

Innovations include:

flexible peg drums;

curved spike cleaning elements;

additional impurity separators;

optimized working distances. These modifications significantly increase cleaning efficiency while minimizing fiber damage.

Conclusions

Textile waste represents a valuable secondary resource capable of supporting sustainable textile production. Cotton and wool waste contain significant amounts of recoverable fibers that can be regenerated and reused in various textile and technical applications.

Modern recycling technologies, including ultrasonic cleaning, hydrodynamic washing, thermal-moisture treatment, and advanced mechanical processing systems, have substantially improved recycling efficiency. Their implementation can reduce environmental impacts, conserve raw materials, and contribute to the transition toward a circular textile economy.

Further technological development and industrial implementation of resource-efficient recycling systems will play a crucial role in achieving sustainable growth within the global textile industry.

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