**Energy-efficient chemical purification technology for fat and wax constituents in greasy wool**

Khadam Jumaniyozov1, Mustafokul Urozov 2, Shavkat Ermatov 2, Nigora Egamberdieva 2, a), Janar Kidirbaeva 3, Jaxongir Axmedov 4 Begdavlat Aliyev 5

1 Research Institute of Fiber Crops, Margilan, Uzbekistan

2 Termiz State University of Engineering and Agrotechnologies, Termez, Uzbekistan

3Berdaq Qoraqalpoq State University, Nukus, Republic of Karakalpakstan, Uzbekistan

4Tashkent Institute of Textile and light Industry, Tashkent, Uzbekistan

5Tashkent State University of Economics, Tashkent, Uzbekistan

a) Сorresponding author: [egamberdiyevanigor1992@gmail.com](mailto:egamberdiyevanigor1992@gmail.com)

**Abstract.** This article examines an energy-efficient chemical cleaning (washing) technology for removing fatty and waxy substances present in natural wool fibers. The types of reagents used in the process, their concentrations, and the influence of technological parameters on cleaning efficiency were analyzed. The surface of raw wool fibers contains fats, wax, dust, suint, and salt deposits, which reduce product quality after fabric manufacturing. Therefore, the study highlights that developing an energy-saving, environmentally safe, and effective chemical washing technology is one of the essential stages in wool processing.

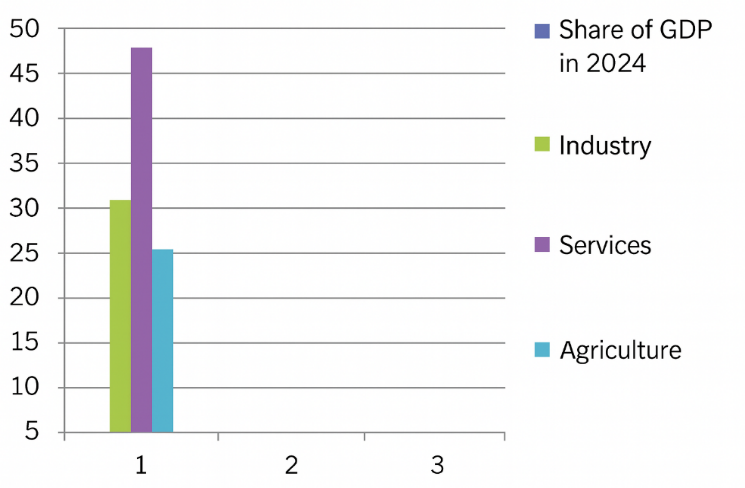
**INTRODUCTION**

The strategic goals of the Republic of Uzbekistan aimed at further strengthening the national economy require the complete modernization of industrial sectors through the introduction of new machinery and technologies, the broad application of scientific and technical achievements, and the implementation of modern, energy-efficient technologies and equipment that ensure high efficiency and labor productivity. The light industry sector in our country has been steadily developing year by year. The introduction of innovative production technologies and the use of modern, energy- and resource-saving equipment contribute to increasing labor productivity, expanding production volumes, and improving product quality indicators.

For many years, Uzbekistan mainly exported wool fiber. Today, however, the country is strengthening its position in the global textile market not only as a supplier of raw materials but also as an exporter of high value-added textile products, particularly finished goods. In this process, the widespread implementation of energy-saving technologies has become an important factor in reducing production costs.

According to the data of the State Committee of the Republic of Uzbekistan on Statistics, the country’s gross domestic product (GDP) increased by 6.5% in 2024 compared to the previous year. The share of the industrial sector in the GDP structure reached 26.4%, which is 1.1 percentage points higher than in 2023. At the same time, the volume of manufacturing industry products amounted to 753.6 trillion soums, showing a 7.7% increase compared to the previous year. The share of the services sector rose to 47.4%, while the share of agriculture, forestry, and fisheries decreased to 19.2%.

These figures demonstrate the growing development rates of the industrial and services sectors in the national economy and indicate that the use of energy-efficient and innovative technologies has become a crucial factor in ensuring economic stability [1].



**FIGURE 1.** GDP Growth Indicators Sector (2024)

Natural wool fibers contain keratin protein as their main component, which provides the fiber with strength, elasticity, and high thermal insulation properties. Wool, being an important protein-based fiber, is highly valued for its mechanical characteristics such as flexibility, high hygroscopicity, and softness. Wool contains large amounts of surface impurities composed of fats, waxes, and other contaminants. In addition, it also includes water-soluble substances such as dried sweat residues as well as inorganic minerals and soil dust [2].

In the textile industry, wool fibers are processed through aqueous treatments. Effective cleaning of wool ensures the production of high-quality fabric. Treatment of wool with supercritical carbon dioxide is considered a modern, environmentally friendly, water-saving, and energy-efficient alternative technology that does not damage the fibers. Supercritical carbon dioxide is an eco-friendly and sustainable solvent that, by reducing water consumption and energy use, serves as an effective means for cleaning wool textiles. It also eliminates the large volume of wastewater and serious environmental pollution typically produced in conventional water-based chemical processing. In addition to this, various chemical treatment methods are also used in combination with wool scouring. Due to its mechanical and chemical properties, wool fiber is resistant to abrasion and wear, which makes it suitable for use as a nonwoven material in flooring and the automotive industry. Compared with cotton, wool fibers are significantly more resistant to tensile stress—they can bend 20,000 times without breaking, while cotton breaks after only about 3,000 bends. These differences, on the one hand, facilitate the removal of impurities from wool, but on the other hand, cause felting and interlocking during washing. This unique property, which is not typical of any other textile fiber, enables the production of dense fabrics such as blankets, filters, and coat materials [3].

The outer surface of the fibers also plays a crucial role in the softness and smoothness of wool, making it one of the smoothest natural textile fibers. Even after natural wool grease is removed during washing, wool fibers retain far less moisture compared to other materials. Because of this inherent low moisture retention, wool fabrics are water-repellent and resistant to water-based stains. Wool fibers can stretch up to 25–30% and still return to their original shape. Their ignition temperature is higher than that of cotton and many synthetic fibers. Even when burned, wool does not melt or drip like synthetic materials. Another important property of wool is its self-extinguishing ability—when the flame source is removed, it stops burning. Moreover, wool releases significantly lower levels of toxic gases during combustion than synthetic materials, making it recommended for use in areas requiring high safety standards.

Despite these advantages, the technical applications of wool remain less explored compared to synthetic fibers. For wool fibers to be successfully used for technical purposes, their natural properties must be effectively utilized or modified to achieve specific functional results. Furthermore, the durability and biodegradability of wool allow it to serve as an ideal ecological material in various technical fields. As a natural fiber material, wool can be used for thermal and acoustic insulation in building facades and roofs, as well as a reinforcing component in polymer-, soil-, or cement-based composite materials.

Wool-based insulation products for buildings are divided into two categories:

1. **Soft materials** – consisting of 100% sheep wool, produced in thicknesses of 4–6 cm, mainly used for thermal insulation of pitched roofs.
2. **Semi-rigid panels** – composed of 70–80% sheep wool and 20–30% polyester, produced in thicknesses of 5–12 cm.

Semi-rigid panels are suitable for wall insulation, and their rigidity is achieved by partial bonding of polyester fibers. According to research findings, the thermal conductivity of biocomposite wool increases with the increase in wool content, which enhances the fiber’s potential for improving energy efficiency in buildings [4]. To improve the structural stability of wool fibers, chemical treatment was conducted. As a result, a protective layer formed on the fiber surface, stabilizing thermal insulation performance and significantly increasing moisture resistance. Although these substances provide beneficial properties such as smoothness, hydrophobicity, and resistance to contamination, they may negatively affect subsequent processing stages—particularly dyeing, nonwoven production, and filtration processes [1].

Therefore, the chemical scouring process is crucial in the initial preparation of wool. The main purpose of this process is to effectively dissolve and remove fats, waxes, and other impurities from the fibers. Although wool is naturally water-repellent, it has excellent moisture absorption capacity, which is an important factor in washing technologies. In recent years, European and Chinese researchers have introduced “eco-washing” technologies based on biological enzymes into industrial practice. These technologies are considered more energy-efficient, electricity-saving, and environmentally safe compared to traditional alkaline washing with sodium hydroxide. During enzymatic washing, fatty and waxy substances are gently decomposed, the mechanical strength of fibers is better preserved, and energy consumption is reduced by 20–30%. Thus, the implementation of energy-efficient “eco-washing” technologies in wool processing not only improves production efficiency and product quality, but also represents an important step in realizing the concept of energy-saving technologies in the textile industry.

***Research Methodology and Tools.*** One of the most important stages in the preliminary processing of wool fibers is chemical washing (scouring). This process is based on the removal of fats, waxes, and dirt from the fibers using emulsifying solutions. The main chemical reaction in the washing process occurs as follows:

RCOOR’+NaOHRCOONa+R’OH

RCOOR’+NaOHRCOONa + R’OH

RCOOR’+NaOH RCOONa+R’OH

During this reaction, the fatty and waxy substances in wool are converted into soap and alcohol, turning them into a water-soluble form. In the scouring process, impurities in the wool are completely removed only during the washing stage. The purpose of the washing process is to clean wool fibres as much as possible from grease, sweat components and other organic contaminants. In traditional washing processes, soap–soda solutions are widely used. Soap solutions possess high emulsifying properties; they penetrate the fibre surface, detach the impurities, and convert them into an emulsion or suspension. Alkaline components (calcium soda, potash) soften the water, increase fibre swelling, and provide the alkaline medium necessary for soap hydrolysis [5].

In this study, the washing process was organised using an energy-saving method. For the experiment, 200 g of natural wool was taken and washed mainly in a soapy solution. The wool was weighed on a scale, cleaned of coarse debris and foreign mineral particles, and then washed. In removing impurities from wool, attention is paid to the type of washing agents, washing temperature, the amount of chemicals used, and the processing time. Optimal conditions must be established for each stage of scouring. If these conditions are not met, i.e., if the selected parameters are not properly applied, fibre damage may occur. During washing, coarse impurities in the raw wool settle at the bottom of the liquid, whereas finer impurities tend to adhere to the fibre surface. Therefore, soap and soda solutions are used in wool scouring. In the washing process, the soapy solution penetrates between the fibre surface and the dirt layer, encapsulates the impurities, dissolves them in water, and removes them [6].

The washing solution temperature ranges from 45–50°C, while the soap concentration varies from 1 to 5 g per litre of water. After each stage, the used solution is settled, the amount of sediment is determined, and energy consumption and heat efficiency are evaluated. In laboratory conditions, parameters used in industrial wool-washing processes were taken as a basis. The amount of soap, soda and other chemicals required in the washing solution depends on the grease–sweat content of the wool. The higher the grease–sweat content, the greater the amount of chemicals needed. Chemical scouring technology plays an important role in saving energy and resources, reducing environmental impact, and preserving the natural physico-mechanical properties of the fibres.

**EXPERIMENTAL RESEARCH**

In addition, the yield of clean wool obtained from unwashed wool is one of the key indicators, as it may affect the quality of the final product in subsequent stages. Furthermore, the cleanliness of the wool depends on the degree of contamination of the raw material, the operating speed of the washing machine components, washing temperature, and other factors. For the washing process to be efficient, the optimal regime must ensure minimal consumption of washing agents while preserving fibre properties [7].The results of the study show that the effectiveness of wool scouring mainly depends on the washing regime, temperature, composition of the solution and the energy efficiency of the technological equipment used. These factors directly influence the quality of the final product obtained in subsequent technological stages. Among these are the level of contamination in the raw wool, operating speed of the washing machine components, washing temperature, solution concentration, and the operating regime of energy-efficient heating systems. Selecting the optimal washing regime reduces the consumption of chemical agents, preserves the natural properties of the fibres, and decreases energy consumption.

Continuous exposure of wool to water, especially hot water, reduces its strength and may even destroy the fibres; water at 80°C has little effect on wool. The destructive effect of water increases at temperatures of 80–110°C. Water at 130°C rapidly dissolves wool, and at 200°C wool dissolves completely. In dry air, wool turns dark at 100°C and begins to degrade. More complete removal of impurities from wool and preservation of its natural properties ensure high-quality indicators in the final product [4,8].

**TABLE 2.** The following components are widely used in the chemical washing of wool

|  |  |
| --- | --- |
| **Substance Name** | Amount (%) |
| **Sodium carbonate (Na₂CO₃)** | *0,5-1,0* |
| **Neutral soap (sodium stearate, C₁₇H₃₅COONa)** | 0,5-1,0 |

The solution temperature should be maintained at 45–50°C, with a pH range of 8.5–9.5. At excessively high temperatures, keratin degradation and fibre weakening may occur. Wool is first prepared by removing dust and mechanical impurities with the help of air. The washing bath is then prepared using the above reagents to make the solution.

During the main washing process, the wool is kept in the solution at 45–50°C for 30–40 minutes. Rinsing is carried out 2–3 times using clean water at 35–40°C. Neutralization is performed using a mild acetic acid solution (0.2–0.3%), which adjusts the pH to a neutral level.

Drying is carried out in an air dryer at 60–70°C, followed by pressing. This process smooths the fibre surface, increases its moisture absorption capacity, and brightens the fibre colour. Hydrophobicity is reduced, facilitating subsequent dyeing and nonwoven fabric production. During reprocessing (pressing), the fibres bond more effectively with one another [9].

**FIGURE 2.** Chemical washing process of wool based on experimental study.

**CONCLUSION**

The rapid development of the light industry sector in our country plays a crucial role in enhancing the national economic potential and increasing the range of competitive finished products in both domestic and international markets. In this context, improving technologies for the high-quality processing of natural fibers, particularly wool, is an urgent issue.

Chemical washing of wool to remove the fats, waxes, sweat components, and other impurities allows the preparation of fibers for subsequent stages while preserving their natural appearance and mechanical properties. This experiment demonstrates that washing in a soap–soda solution at 45–50°C with a pH range of 8.5–9.5 provides the most effective results. Under these conditions, almost all dirt, fats, and waxy substances are removed from the fibers, while their elasticity, smoothness, and strength are maintained. As a result, the wool fibers become brighter, their hydrophobicity decreases, and subsequent dyeing and nonwoven fabric production processes are facilitated [10].

The rapid development of the light industry sector in the Republic of Uzbekistan contributes significantly to increasing the country’s economic potential, creating new jobs, and expanding the production of competitive finished products in domestic and foreign markets. From this perspective, improving the technologies for processing natural fibers, especially wool, and organizing them based on energy-efficient production systems is an important scientific and practical issue [11,12].

Conducting the washing process in an energy-saving mode has been shown to reduce energy consumption by 15–20% while also saving water and washing agents. Consequently, wool fibers become brighter, and their hydrophobicity decreases, simplifying the preparation of dyed nonwoven fabrics and filtration materials. Overall, the proper selection and implementation of an energy-efficient chemical washing technology in optimal conditions significantly improve the quality of the final product. This, in turn, enhances the export potential of Uzbekistan’s textile industry and contributes to the production of environmentally friendly, high-quality products.

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