TASHKENT STATE UNIVERSITY OF ECONOMICS

International journal of topics

INNOVATION SCIENCE AND TECHNOLOGY

ISSUE 9, PART I / SEPTEMBER 2026

Acceptance of papers

Acceptance of papers

Published monthly

Topics

economics, technology, social sciences

INNOVATION SCIENCE AND TECHNOLOGY
SOCIAL, ECONOMIC, SCIENTIFIC, AND TECHNICAL ACADEMIC JOURNAL

Google Scholar

doi Digital Object Identifier

RePEc RESEARCH PAPERS IN ECONOMICS

ISSN 3060-5229

Electronic publication, Issue 9.
Approved for publication on September, 2026.

THE SCIENTIFIC-POPULAR ELECTRONIC JOURNAL **"INNOVATION SCIENCE AND TECHNOLOGY"** HAS BEEN REGISTERED UNDER THE NUMBER **C-5669633** BY THE AGENCY FOR INFORMATION AND MASS COMMUNICATIONS (AOKA) OF THE REPUBLIC OF UZBEKISTAN, EFFECTIVE FROM OCTOBER 9, 2024.

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The scientific electronic journal “Innovation Science and Technology” has been included in the list of scientific publications recommended for the publication of main scientific results of dissertations for the award of PhD and DSc degrees in economics and technical sciences, in accordance with the Resolution No. 370 of the Presidium of the Higher Attestation Commission of the Republic of Uzbekistan, dated May 8, 2025.

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CHARGING OF SYNTHETIC FIBERS AND IMPROVEMENT OF EMULSION

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Abstract. A newly improved method for the antistatic treatment of synthetic fibers using an emulsification device is proposed. The main influencing factors in the device were identified as the polarized electric field voltage, the distance between the field-generating electrodes, and the emulsion concentration, with their variation ranges determined experimentally. Analysis of the mechanical properties of yarns produced from cotton–nitron blends showed that cotton fiber had lower elongation than nitron fiber. Yarn strength was considerably higher in the 80/20 cotton–nitron blend, whereas it was lower in the 50/50 cotton–nitron blend. It was also found that, in cotton–nitron blends, yarn stiffness decreases as the proportion of nitron fibers increases to 50%. The proposed emulsification device enables the effective processing of fibrous materials, reduces fiber electrification, and improves the quality of the resulting yarn. Synthetic fibers exhibit dielectric and polarization properties, and the improved emulsification method was found to be highly effective in reducing their electrification. To obtain high-quality yarn from cotton–nitron blends, a technology for producing high-strength yarn from blends containing 20% and 30% nitron fibers treated using the improved emulsification method was developed.

Keywords: synthetic fibers, antistatic treatment, emulsification device, polarized electric field, cotton–nitron blend, mechanical properties, yarn strength, elongation, X-ray diffraction (XRD), electrostatic charge, dielectric properties.

Аннотация. Предложен усовершенствованный метод антистатической обработки синтетических волокон с использованием эмульсирующего устройства. В качестве основных факторов, влияющих на работу устройства, определены напряжение поляризованного электрического поля, расстояние между электродами, создающими поле, и концентрация эмульсии; диапазоны их изменения установлены экспериментально. Анализ механических свойств пряжи, полученной из хлопково-нитроновых смесей, показал, что удлинение хлопкового волокна ниже, чем нитронового. Прочность пряжи была значительно выше при соотношении хлопка и нитрона 80/20 и ниже при соотношении 50/50. Установлено также, что в хлопково-нитроновой смеси жесткость пряжи снижается при увеличении доли нитроновых волокон до 50%. Предлагаемое эмульсирующее устройство обеспечивает эффективную обработку волокнистых материалов, снижает электризацию волокон и способствует повышению качества получаемой пряжи. Синтетические волокна обладают диэлектрическими и поляризационными свойствами, а усовершенствованный способ эмульсирования показал высокую эффективность в снижении их электризации. Для получения высококачественной пряжи из хлопково-нитроновых смесей разработана технология производства высокопрочной пряжи из смесей, содержащих 20% и 30% нитроновых волокон, обработанных усовершенствованным методом эмульсирования.

Ключевые слова: синтетические волокна, антистатическая обработка, эмульсирующее устройство, поляризованное электрическое поле, хлопково-нитроновая смесь, механические свойства, прочность пряжи, удлинение, рентгеновская дифракция (XRD), электростатический заряд, диэлектрические свойства.

Annotatsiya. Sintetik tolalarga antistatik ishlov berishning emulsiyalash qurilmasidan foydalanishga asoslangan takomillashtirilgan usuli taklif etilgan. Qurilmaning ishlashiga ta’sir etuvchi asosiy omillar sifatida qutblangan elektr maydoni kuchlanishi, maydon hosil qiluvchi elektrodlar orasidagi masofa va emulsiya konsentratsiyasi belgilangan hamda ularning o‘zgarish oraliqlari tajriba asosida aniqlangan. Paxta–nitron aralashmasidan olingan iplarning mexanik xossalari tahlili paxta tolasining uzayishi nitron tolasiga nisbatan past ekanligini ko‘rsatgan. Ipning mustahkamligi 80/20 nisbatdagi paxta–nitron aralashmasida sezilarli darajada yuqori, 50/50 nisbatdagi aralashmada esa nisbatan past bo‘lgan. Shuningdek, paxta–nitron aralashmasida nitron tolalari ulushi 50% gacha oshirilganda ipning qattiqligi kamayishi aniqlangan. Taklif etilgan emulsiyalash qurilmasi tolali materiallarga samarali ishlov berish, tolalarning elektrlanishini kamaytirish va ulardan olinadigan ip sifatini yaxshilash imkonini beradi. Sintetik tolalar dielektrik va qutblanish xususiyatlariga ega bo‘lib, ularning elektrlanishini kamaytirishda takomillashtirilgan emulsiyalash usulining yuqori samaradorligi aniqlangan. Paxta–nitron aralashmalaridan yuqori sifatli ip olish maqsadida takomillashtirilgan usulda emulsiyalangan, tarkibida 20% va 30% nitron tolalari mavjud aralashmalardan yuqori mustahkamlikka ega ip ishlab chiqarish texnologiyasi ishlab chiqilgan.

Kalit so‘zlar: sintetik tolalar, antistatik ishlov berish, emulsiyalash qurilmasi, qutblangan elektr maydoni, paxta–nitron aralashmasi, mexanik xossalar, ip mustahkamligi, uzayish, rentgen difraksiyasi (XRD), elektrostatik zaryad, dielektrik xossalar.

INNOVATION SCIENCE AND TECHNOLOGY

INTRODUCTION

The expansion of the range of yarns, one of the products of the textile industry, and the sharp increase in demand for them have led to improvements in equipment used in technological processes.

It was necessary to identify all the factors affecting the production process, analyze them, and find appropriate solutions to fulfill the tasks set by the President and the Government of the Republic of Uzbekistan.

The generation and accumulation of static charges in chemical fibers and yarns are referred to as electrification. During the mechanical processing of fibers and yarns, friction occurs between the materials themselves and between the materials and metal surfaces, resulting in the generation of electric charges, i.e., intensive electrification.

Synthetic fibers, in particular, are highly susceptible to electrification. As a result, the fibers may undergo changes that affect the stability of technological processes.

LITERATURE REVIEW

Therefore, the study of electrification remains a relevant issue to which numerous studies have been devoted [1–15].

The rapid growth in the production of synthetic fibers within the overall balance of textile raw materials requires further improvement in their processing technologies at textile enterprises.

It has been noted that the introduction of high-speed processing technologies for such fibers, particularly polyester and polyacrylonitrile (Nitron) fibers, requires appropriate consideration of the formation of static electric charges in the fibers [2].

The use of open-end and ring-spinning machines to produce yarn from blends of cotton and chemical fibers, particularly polyester and Nitron fibers, offers several advantages. At the same time, studies have shown the importance of effectively managing static electricity during the preparation of semi-finished products for spinning [3].

Static electrification of fibers, which may influence the speed of technological processes, is observed primarily when individual fibers have relatively weak interconnections and move at higher speeds.

It has been noted that electrostatic charges are formed as a result of mutual friction between fibers during the carding process. In most cases, these charges are relatively insignificant in relation to the mass of the fibers in contact with the working parts of the processing equipment.

Charged fibers may adhere to the working parts of machines, affecting the movement of fibrous material. Appropriate management of this phenomenon contributes to maintaining structural uniformity in the resulting product and ensuring the stability of the technological process [4].

J. I. Frenkel presented an alternative scientific interpretation of the existing theory of dielectric electrification. He considered it necessary to further develop approaches to explaining the electrification of dielectrics rather than directly applying a modified version of the theory developed for metals.

This conclusion is supported by the existence of a triboelectric voltage series for fibrous materials, which characterizes the electrostatic properties of different fibers.

The determination of the surface charge density of fibers is based on theoretically substantiated and experimentally verified laws describing the relationship between charge densities on the surface of a flat material.

The velocity of the material is denoted by V, while the specific surface resistance is represented by Rg [5–6]. Due to the extensive separation of fibers during processing on carding machines, almost every fiber tuft is exposed to the card-clothing teeth and separates from them at high speed.

Under these conditions, the time available for charge dissipation is limited, while the degree of fiber separation is considerable, creating favorable conditions for increased fiber electrification. Appropriate control of this phenomenon contributes to the stability of the carding process and the uniform formation of card sliver.

When the charge reaches a certain level, the interaction between fibers changes, causing them to move toward the edges. In this case, tufts of synthetic fibers may adhere during their movement through the funnel, which can influence the continuity of sliver formation.

Some studies have found that the general limiting charge value for synthetic fibers is 10^{-4} C/g. When the charge exceeds 10^{-4} C/g, electrostatic interference may occur. Depending on the unit area, a charge-density value of 4×10^{-2} C/cm^2 corresponds to the previously reported results and is also applicable to processing on a carded-fiber production line using bunker feeding for card sliver.

It has been reported that increased electrification may influence the formation of the roving in the formation channel. It should be noted that, because fibers in the sliver are more strongly bonded, electrostatic interference is observed at higher charge densities.

During processing on the draw-frame machine, it was found that appropriate technological conditions should be maintained to effectively manage fiber electrification.

The technological characteristics that arise during the processing of synthetic fibers can be effectively managed through the use of different emulsions, thereby contributing to improvements in yarn quality.

In the processing of synthetic fibers, V. N. Vanchikov [8] noted that increasing the speed of the working parts of carding machines and the adhesion of synthetic fibers to surfaces during continuous carding may influence the level of unevenness, indicating the importance of applying appropriate measures to improve uniformity.

The specific volume of the electric field characterizes the transmission of electric charges in a substance under external influence. In the analysis of physical models, it is important to understand the passage of electric current through polymers and the dependence of force when using these materials.

It should be noted that the passage of electric current through a material is associated with fundamental processes such as the dissociation and ionization of molecules, the recombination of atoms and charge carriers, directional diffusion, the transfer or movement of charged particles in an electric field, and the establishment of different polarities between two media.

Due to the presence of free charges in synthetic polyester and Nitron fibers, the formation of a positive free charge on one part of the fiber surface and a negative free charge on another part under the influence of an external electrostatic field has been noted in [9–10].

Fibers and yarns are characterized by their ability to generate and accumulate static electricity. During mechanical processing, fibers and yarns can become highly electrified as a result of friction against each other and against machine components. Fibers and yarns carrying identical charges can repel each other, thereby influencing the technological process. Chemical fibers and yarns, including chlorine, acetate, and nylon fibers, demonstrate particularly pronounced electrification properties. Natural fibers, such as wool and silk, can also become electrified, although to a lesser extent.

The electrification of synthetic yarns can be reduced by increasing relative humidity and coating them with an oil film or antistatic emulsions containing hygroscopic salts, polyhydric alcohols, soaps, cations, and other substances. In addition, ionization devices can be used to regulate fiber electrification at the points where the yarns move. The surface charge density of the fibers was determined at relative humidity levels of 44% and 64%, respectively. These data indicate that the highest levels of electrification occur in chlorine, acetochlorine, and Anide yarns. With an increase in relative humidity from 44% to 64%, the surface charge density of Nitron and acetate yarns decreases by almost 32 times. A significant decrease in the electrification of other yarns was also reported in [11–12].

Particular attention is paid to improving product quality and production efficiency. In addition, these synthetic fibers have high mechanical resistance and do not react with organic solvents. Their specific electrical resistance ranges from 1 Ohm to 10 Ohm, above which other substances are not affected. Nitron fibers are weather-resistant and exhibit high resistance to strong acids. They are widely used in the manufacture of carpets, fur coats, and filter materials. Studies [13–14] have noted that the widespread use of chemical fibers in blends with natural fibers contributes significantly to improving the quality and appearance of new textile products.

The electrical conductivity of yarns is considered in describing the movement of electric charges under the influence of an external electric field [15].

The conductivity of fibers is associated with currents flowing through the yarn material and depends on current density, exposure time, electric-field strength, temperature, composition, structure, size, and shape. Most textile fibers and yarns are dielectrics, and the fundamental laws governing dielectric materials are applicable to them. The current in yarns decreases over time due to the movement of bound charge dipoles and the occurrence of processes near the electrode. When dielectrics composed of polar molecules are placed in an electric field, forces acting on each dipole in the direction of the field strength are generated. However, complete rotation is limited by thermal motion. As a result, positive charges move in the direction of the electric field, while negative charges move in the opposite direction. In general, all types of polarization result in the formation of positively bound charges at the points where the external electric-field lines exit the dielectric and negatively bound charges at the points where they enter the dielectric [16].

Because conductivity is relatively high, currents associated with charge dissipation occur at high voltage values in conductors. Therefore, the electric-field strength in conductors is relatively low. A strong electric field can persist for a longer period primarily in dielectrics, where intermolecular forces bind charge carriers and the number of free electrons is limited. A strong electric field can also occur in a vacuum. One of the physical properties of a vacuum is its ability to contain an electromagnetic field. Electric displacement occurs under the influence of voltage in a medium in which an electric field is generated. In the molecules of some dielectrics, the positive nuclei of atoms move in one direction, while the electron orbits shift in the opposite direction. In other dielectrics, molecules consist of positive and negative charges (dipoles) spatially separated from each other; in such dielectrics, the dipoles rotate under the influence of an electric field. Both charge displacement and dipole rotation constitute dielectric polarization.

It is known that drafting and doubling processes are carried out on draw-frame machines. The main function of draw-frame machines is to draft and attenuate the product while straightening and parallelizing the fibers. When processing blends of synthetic and cotton fibers, the specific electrostatic properties of Nitron fibers require particular attention during carding after several processing stages. Drafting and doubling processes are carried out on draw-frame machines. This is associated with the fact that Nitron fiber has a water absorption capacity of only 2%. Consequently, static charging of Nitron fibers may occur during carding when the emulsion does not completely cover the fiber surface. These differences become apparent when the draw-frame sliver is first passed through the draw-frame machine.

In the draw-frame machine, the sliver is introduced into the drafting device by means of a feeding pair located on the surface of the feed table. The elongated and attenuated product is then directed toward the compaction opening and, after being formed into a sliver, passes through the guide channel and flattening rollers. The sliver is subsequently drawn by the rollers and placed into cans. The movement of charged fibers toward the condenser may slow due to electrostatic interaction on the surface of the sliver feed table during these processes, which can affect sliver uniformity and continuity. This phenomenon was effectively controlled during the processing of emulsified fibers in the blend, demonstrating the positive effect of emulsification [17].

RESEARCH METHODOLOGY

The reason for this is that the water absorption of Nitron fiber is only 2%. Therefore, it was observed that Nitron fibers emulsified without passing through the polarized electric field become statically charged during carding. Some of these fibers remain in the sliver and other parts of the carding machine, resulting in surface unevenness and the formation of neps.

Today, the rapid growth of synthetic fiber production in the overall balance of textile raw materials requires further improvement in their processing technologies at textile enterprises. With the introduction of high-speed processing technologies for such fibers, especially synthetic polyester and Nitron fibers, increased static electrification in the fibers requires appropriate technological measures. At the same time, the demand for chemical-fiber and blended-fiber yarn products is growing in the textile industry.

Several sources have indicated that the electrification of chemical fibers during spinning can influence yarn quality. To effectively manage this phenomenon, emulsification using various agents has been introduced. In particular, manual, mechanized, and chamber emulsification methods have been applied in production.

It is known that the electrical resistance of fibrous materials has been investigated in emulsification studies. It has been shown that the lower the electrical resistance of the fibrous material being processed, the lower its electrification and the higher the charge leakage rate. It should be noted that the electrical resistance of individual fibers is of less practical significance than the resistance of the fiber mass because, in the latter case, contacts are formed between the fibers. It has also been noted that the resistance of the fiber mass can be measured at any stage of fibrous-material processing.

Although significant progress has been achieved in addressing issues related to synthetic-fiber processing, the introduction of new technological processes, improvements in equipment efficiency, and increased volumes of synthetic-fiber processing create opportunities for further technological development. Reliable quantitative and qualitative data on the degree of electrification of yarns obtained during the processing of polyamide fibers make it possible to accurately assess the effects of static electric charges and develop effective measures for their management.

Unlike processes in which dielectric polarization is reversible, electrical conductivity results in the establishment of a residual current due to the movement of free charges.

ANALYSIS AND RESULTS

The quality of yarn obtained from fibrous materials can be improved by reducing electrification and enhancing the quality of emulsification through the processing of fibers in a high-voltage electric field. To achieve this, the surface of the fibers must be completely covered with an emulsifier. To address this issue, a special device was developed in the form of a conveyor belt mounted on a frame and positioned at the outlet of the loading hopper. The device is equipped with potential and grounded electrodes that enable the fibrous material to be processed in a high-voltage electric field. The processing agent is supplied after the electrode impact zone and before the heater, which dries the fibrous material following emulsification.

In a continuous technological process, the fibers are processed in a high-voltage electric field for a specified period while being transported by a conveyor belt. They are then emulsified and dried using a heater. When processed in a high-voltage electric field, the fibers acquire an electric charge. As a result, the fiber surface is completely covered with the emulsion, adhesion to metal surfaces is reduced, and the quality of the spun yarn is improved. The fibrous material emulsification device is shown in Figure 1.

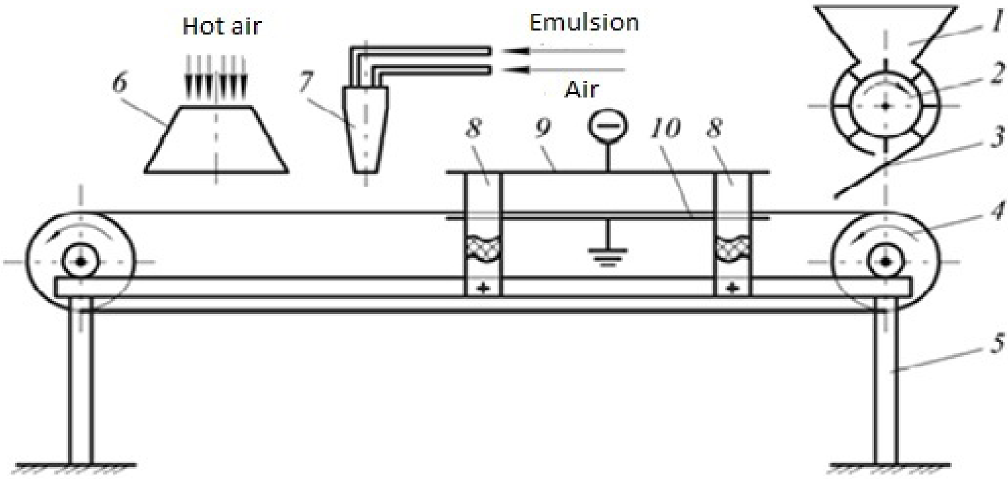

Figure 1. Fibrous Material Emulsification Device

The device can be used in the textile industry for the emulsification of fibrous materials and the improvement of yarn quality. Processing fibrous materials in a high-voltage electric field makes it possible to reduce electrification and, consequently, improve the quality of the resulting yarn. The fibrous material emulsification device is coaxially mounted in a horizontal cyclone chamber with conical inlet and outlet tubes and is equipped with sprayers that supply the processing medium. The device is designed as a conveyor belt mounted on a frame. It is installed at the outlet of the loading hopper and equipped with potential and grounded electrodes that enable the fibrous material to be processed in a high-voltage electric field before emulsification. A sprayer that supplies the processing agent is positioned in front of a heater that dries the emulsified fibrous material after it passes through the electrode impact zone.

The fibrous material emulsification device includes a loading hopper (1), feeder (2), inclined board (3), conveyor belt (4), frame (5), heaters (6), injectors (7), dielectric supports (8), potential electrode (9), and grounded electrode (10). The loading hopper (1), feeder (2), inclined board (3), and conveyor belt (4) are located on the frame (5) and are driven by an electric motor, which is not shown in the figure. The dielectric supports (8) are connected to the frame (5) by bolts and are equipped with the potential electrode (9) and grounded electrode (10). In this case, the potential electrode (9) is mounted above the conveyor belt (4), while the grounded electrode is positioned below it. Depending on the physical and mechanical properties of the fibrous materials, high voltages of different magnitudes are applied to the electrodes. For this purpose, devices are mounted on the dielectric supports to adjust the distance between the electrodes. After the potential (9) and grounded (10) electrodes, injector guides (7) are installed to apply the emulsion (processing agent) using compressed air. At the end of the conveyor belt (4), heaters (6) are installed to supply hot air to the emulsified fibrous material.

The fibrous material emulsification device operates as follows. Using the feeder (2) and inclined board (3), the fibrous material is uniformly fed onto the moving conveyor belt (4). At this stage, depending on the physical and mechanical properties of the fibrous materials, a high voltage is supplied from the power source to the potential (9) and grounded (10) electrodes. The fibrous material passing between the potential (9) and grounded (10) electrodes is polarized, and the fibers are aligned in the direction of the high-voltage electric-field lines. After leaving the high-voltage electric field, the fibrous material is emulsified with a processing agent through the injector (7) and an air stream. Following emulsification, the fibrous material is continuously dried using the heater (6) and then transferred to the subsequent yarn-forming process.

As a result, the fiber surface is completely coated with the emulsion and dried using the heater, forming a thin protective layer on the fiber surface that helps regulate excessive charging. This reduces the adhesion of fibrous material to the metal parts of the machine during processing, contributes to the control of electrification, and improves the quality of the spun yarn.

Multivariate mathematical planning methods are widely used in studies of technological equipment and the operating parameters of various devices. This is because independent factors can simultaneously influence equipment efficiency to varying degrees. It is known that synthetic fibers are initially processed and subsequently subjected to antistatic treatment, i.e., emulsification, to obtain the finished product. A special device was developed to improve the emulsification process of synthetic fibers and increase its efficiency. Its operating principle is based on spraying an emulsion onto synthetic fibers after they have passed through a polarized electric field.

Preliminary experiments showed that several factors influence the properties of blended yarn obtained by emulsifying synthetic fibers in the emulsification device. These factors include the magnitude of the voltage applied to the electrodes of the device, the distance between the electrodes, and the percentage of emulsion. The interaction between the factors was taken into account, and the values of their levels were selected. In the study, before processing a bundle of synthetic fibers, the fibers are passed through a polarized region to regulate weak charges on their surfaces. The weak charges are replaced by positive charges, after which the fibers are treated with a negatively charged special liquid. Due to the alkalinity of the liquid applied to the fiber surface, its decomposition into particles is illustrated in Figure 2, where (1) represents a bundle of synthetic fibers and (2) represents the special liquid.

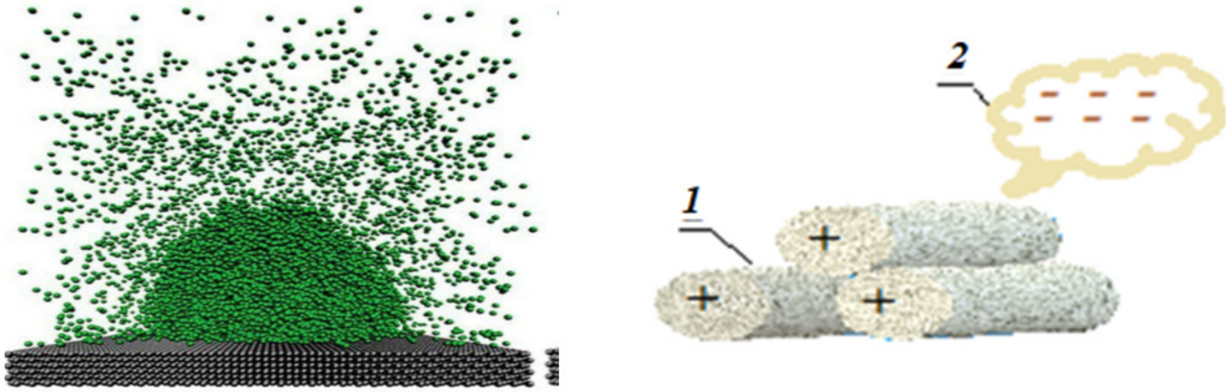

Figure 2. Attraction of Dielectric Particles to Charged Parts of Synthetic Fibers

The bound charge associated with dielectric polarization should be distinguished from the charge present on the surface of the fibers. The surface charge of the fibers consists of a certain amount of free electric charge that can persist for a considerable period independently of the electric field. In most cases, it is generated by friction between two materials, in which case the body with the higher dielectric constant becomes positively charged.

Nitron fibers emulsified using the improved method were blended with cotton fibers at cotton–Nitron ratios of 80/20, 70/30, 60/40, and 50/50, and the resulting blended yarns were tested using the USTER® device. The Rkm and CV{Rkm} results of the obtained yarns are presented in Table 1.

Table 1
Mechanical properties of cotton-nitron blended yarn Rkm, SV {Rkm}.

№	Option of blending	Parameters	
		R_{km}	CV{R_{km}}.
1	80/20	14.1	9
2	70/30	11.6	6.9
3	60/40	10.3	10
4	50/50	7.8	7.6

Analysis of the mechanical properties of the yarns obtained from cotton–Nitron blends showed that the elongation of cotton fiber was lower than that of Nitron fiber, while yarn strength was considerably higher in the 80/20 cotton–Nitron blend and lower in the 50/50 cotton–Nitron blend. It should be noted that, in cotton–Nitron blends, yarn stiffness decreases as the proportion of Nitron fibers increases to 50%. The results of the analysis of the Rkm and CV{Rkm} indicators are presented in the histograms in Figures 3 and 4.

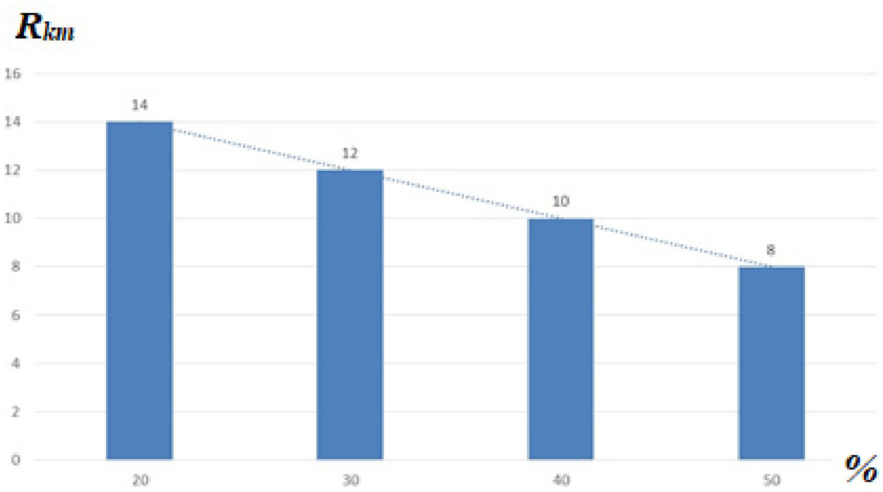

Figure 3. Rkm index of yarns obtained from cotton-nitron blending

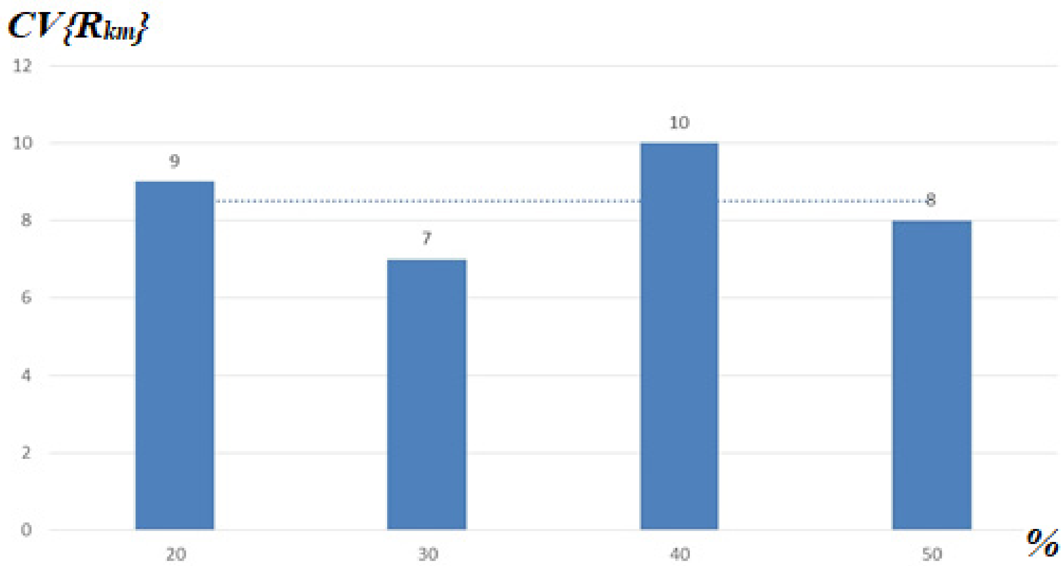

Figure 4. SV {Rkm} index of yarns obtained from cotton-nitron mixture

Thus, to obtain high-quality yarn from cotton–Nitron blends, an improved technology for producing high-strength yarn from blends containing 20% and 30% Nitron fibers treated using the improved emulsification method was developed.

CONCLUSIONS AND RECOMMENDATIONS

The implementation of the novel high-voltage polarized electric-field emulsification device offers a robust technological solution for processing synthetic fibrous materials, particularly polyester and polyacrylonitrile (Nitron) fibers. By effectively neutralizing electrostatic charges and ensuring the formation of a continuous and uniform emulsion film on the fiber surfaces, the proposed device helps prevent fiber adhesion to the metal parts of machines, promotes structural uniformity, and enhances process stability during high-speed carding and drafting operations.

Given that synthetic fibers possess distinct dielectric characteristics and inherent polarization properties with exceptionally low surface friction, conventional mechanical emulsification methods may provide opportunities for further improvement in controlling static charge accumulation. The integration of an electrostatic polarization zone prior to emulsion spraying modifies the surface charge distribution, replacing weak charges with controlled polarity and enabling deep and uniform wetting. This mechanism significantly reduces fiber electrification and contributes to the stability of the subsequent spinning process.

Comprehensive mechanical evaluations of cotton–Nitron blended yarns using USTER testing equipment demonstrated clear performance trends across various blend ratios. The results established that optimal breaking strength (Rkm) and structural integrity are achieved in compositions containing **20% and 30% Nitron** (80/20 and 70/30 cotton–Nitron ratios). At the same time, increasing the Nitron proportion to 50% results in changes in overall yarn strength and material stiffness, indicating the importance of selecting an appropriate blend ratio.

Based on these scientific findings, the optimized technology utilizing a 20–30% Nitron blend treated using the enhanced electrostatic emulsification method is recommended for industrial textile manufacturing. The industrial application of this approach can contribute to improved yarn quality, enhanced mechanical properties, and compliance with modern industrial production standards.

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Proofreader: Zokir ALIBEKOV

Layout and Designer: Oloviddin Sobir ugli

2026. № 9

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