

ABSTRACT

of the dissertation by Zhanerke Borkulakova on the topic:
“Development of a Technology for the Use of Wool Waste as Environmentally
Friendly Insulating Non-Woven Materials”, submitted for the degree of Doctor
of Philosophy (PhD) in the field of 8D072 – Manufacturing and Processing
Industries, Educational Program 8D07212 – Innovative Textiles

Relevance of the research topic. In the context of modern scientific and industrial development, the rational use of natural resources, the reduction of industrial waste, and the transition toward sustainable and environmentally oriented production have become increasingly important. One of the underutilized types of natural raw materials is coarse sheep wool, which, due to its large fiber diameter, high stiffness, structural heterogeneity, and low spinnability, is practically not used in conventional textile manufacturing. The lack of industrial utilization of coarse wool results in it being regarded as a by-product or waste of animal husbandry, thereby creating an additional environmental burden associated with its accumulation and improper disposal.

This issue is particularly relevant for countries with well-developed sheep farming, especially Kazakhstan, where a significant proportion of livestock consists of fat-tailed coarse-wool sheep breeds raised primarily for meat production. As a result, substantial amounts of coarse wool are generated annually without effective industrial utilization. The inefficient use of this renewable natural resource leads not only to economic losses but also to increased environmental risks associated with the storage and disposal of organic waste.

At the same time, wool is a natural, renewable, and biodegradable material with a unique combination of thermophysical, mechanical, and hygroscopic properties. Its fibrous structure provides excellent thermal insulation, moisture regulation, and air permeability, making it a promising raw material for environmentally friendly thermal insulation materials. Moreover, the biodegradability of wool after the end of its life cycle supports closed-loop biological cycles and aligns with the principles of circular economy and sustainable development.

A review of the scientific literature indicates that natural fibers are widely studied as raw materials for thermal insulation applications. Wool is among the most efficient natural insulating fibers. Compared with other natural fibers, it exhibits one of the lowest thermal conductivity values (approximately 0.033 W/mK), which is attributed to its complex internal structure, air-filled cavities, crimped morphology, and high elasticity. However, the thermal performance of fibrous materials depends not only on the thermal conductivity of individual fibers but also on the structure of the formed material. The main contribution to thermal insulation is provided by air trapped within pores and inter-fiber spaces due to its significantly lower thermal conductivity.

Wool-based nonwoven materials demonstrate low effective thermal conductivity values comparable to synthetic insulation materials. The combination of low density, high porosity, and a highly crimped fiber structure creates a stable air layer, resulting in thermal conductivity values ranging from 0.038 to 0.054 W/mK,

which corresponds to the upper range of mineral-based insulation materials. The formation of such a porous structure is strongly influenced by technological production parameters. However, analysis of the literature shows that the influence of needle-punching parameters, the structure of multilayer nonwoven materials, and the ratio of coarse to semi-coarse wool fibers on the thermal performance of fully natural wool-based nonwovens remains insufficiently studied. In addition, there is a lack of research on the use of wool from Kazakh fat-tailed sheep breeds as raw material for thermal insulation materials.

Aim of the study. The aim of the research is to develop and experimentally substantiate technological regimes for the production of environmentally friendly multilayer nonwoven materials based on coarse and semi-coarse sheep wool for thermal insulation applications, as well as to identify the relationships between the structure of nonwoven materials and their key properties depending on technological parameters.

Research objectives:

1. To conduct a systematic review of the literature and statistical data on the use of wool as a raw material for thermal insulation materials, including production volumes at both national and global levels.

2. To investigate the properties of wool and methods of manufacturing multilayer nonwoven materials, and to identify the main factors affecting thermal insulation performance.

3. To select and prepare raw materials and determine an appropriate fiber bonding method for the formation of nonwoven materials.

4. To develop an experimental research program using design of experiments methods to study the influence of technological parameters on material properties.

5. To fabricate multilayer needle-punched nonwoven materials based on coarse wool by varying punching frequency, number of layers, and coarse-to-semi-coarse wool ratio in order to investigate structure formation and its influence on thermal, functional, and physico-mechanical properties.

6. To establish quantitative relationships between warmth retention coefficient, tensile strength, and air permeability of multilayer nonwoven materials and their technological and structural parameters.

7. To develop scientifically substantiated recommendations for technological regimes for producing environmentally friendly nonwoven thermal insulation materials.

Object of the study – nonwoven materials based on coarse and semi-coarse sheep wool used for thermal insulation purposes.

Subject of the study – thermal insulation and physico-mechanical properties of multilayer needle-punched nonwoven materials (warmth retention, tensile strength, air permeability) and their relationships with technological parameters of material formation (punching frequency, number of layers, and wool composition ratio).

Scientific novelty of the research:

– technological regimes for producing environmentally friendly needle-punched thermal insulation nonwoven materials based on coarse and semi-coarse

wool of Kazakh fat-tailed sheep breeds have been developed and scientifically substantiated;

- the combined influence of punching frequency, number of layers, and fiber composition ratio on the structure formation and thermal insulation properties of multilayer nonwoven materials has been investigated;

- relationships governing variations in the warmth retention coefficient, tensile strength, and air permeability of multilayer nonwoven materials depending on structural characteristics and technological process parameters have been established.

Practical significance of the study. The obtained experimental results can be used in the development and improvement of technologies for manufacturing environmentally friendly multilayer needle-punched nonwoven thermal insulation materials for construction and technical applications. The proposed methodology for predicting physico-mechanical and thermal properties based on structural and technological parameters enables rational selection of production regimes. The materials were manufactured under industrial conditions, demonstrating the practical applicability of the proposed technological solutions.

The study also contributes to the industrial utilization of coarse wool from Kazakh fat-tailed sheep breeds, previously considered a low-value by-product of animal husbandry, thereby reducing environmental impact and economic losses through more efficient use of renewable raw materials and the reduction of waste volumes.

The practical significance of the work is confirmed by an implementation act obtained under operating industrial conditions. The research was carried out within the framework of program-targeted funding.

The **research methods** included: literature analysis; industrial fabrication of multilayer needle-punched nonwoven materials; design of experiments methods; laboratory testing methods for determining thermal insulation and physico-mechanical properties; mathematical statistics and regression analysis for experimental data processing; and computer-based data visualization and graphical representation of results.

Main provisions submitted for defense:

- experimental results establishing relationships between structural formation of multilayer needle-punched nonwoven materials and technological parameters (punching frequency, number of layers, and fiber composition ratio);

- experimental results on the combined influence of technological parameters on thermal and physico-mechanical properties (warmth retention coefficient, tensile strength, and air permeability);

- technological regimes for producing environmentally friendly needle-punched thermal insulation nonwoven materials based on coarse and semi-coarse wool from Kazakh fat-tailed sheep breeds.

Relation to research grant projects. The study was carried out within the framework of program-targeted funding project BR24992867 “Development of resource-saving technologies for the development and management of water resources and processing industries in Kazakhstan, creation of an innovative

engineering center”, funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan.

Approbation of the results. The main results of the dissertation were presented and discussed at international scientific conferences: International Scientific Conference No. 5 “Progress in Science” (Brussels, Belgium, 2024); International Scientific and Technical Conference “Innovative High-Tech Solutions and Current Problems in Textile and Light Industry (TEXTILE AND LIGHT INDUSTRY – 2024)” (Fergana Polytechnic Institute, Uzbekistan, 2024).

Publications. The main results of the research were published in 6 scientific papers: 1 article in an international peer-reviewed journal indexed in Scopus/Web of Science (percentile 80, Q1); 3 articles in journals recommended by the Committee for Quality Assurance in Science and Higher Education of the Ministry of Science and Higher Education of the Republic of Kazakhstan; and 2 articles in conference proceedings.

Structure and scope of the dissertation. The dissertation consists of an introduction, four chapters, a conclusion, a list of 146 references, and appendices. The work is presented on 91 pages, includes 26 figures and 28 tables.

Main Content of the Dissertation. The dissertation is focused on the experimental investigation of the influence of technological parameters used in the formation of multilayer needle-punched nonwoven materials based on underutilized coarse wool from fat-tailed sheep breeds on their thermal insulation and physico-mechanical properties.

The introduction substantiates the relevance of the research topic, reflecting its significance for the current state and future development of the studied field. The aim and objectives of the research are formulated, and the object and subject of the study are defined, thereby establishing the scientific direction and scope of the work. The scientific novelty of the dissertation is presented through the investigation of the influence of technological parameters involved in the formation of multilayer needle-punched nonwoven materials on their thermal insulation and physico-mechanical properties, as well as through the development of technological regimes for producing environmentally friendly thermal insulation materials based on coarse and semi-coarse wool. The main provisions submitted for defense are highlighted, reflecting the results of experimental investigations and the practical aspects of the study.

The introduction also presents the methodology and research methods employed in the study, including analytical, experimental, and computational-statistical approaches, as well as the rationale for their selection in terms of reliability and reproducibility of the obtained results.

The practical significance of the work is emphasized through the potential application of the obtained results in the development and improvement of technologies for manufacturing environmentally friendly thermal insulation nonwoven materials based on wool raw materials for construction and technical applications, as well as through the involvement of coarse wool in industrial processing.

In addition, information on the author's publications confirming the approbation of the research results in scientific journals and conference proceedings is provided. The introduction concludes with a description of the structure and scope of the dissertation, including the number of chapters, sections, figures, tables, and appendices, providing a comprehensive understanding of the logic and sequence of the research presentation.

The first chapter presents a comprehensive review of the current state of scientific research devoted to the utilization of wool raw materials and technologies for producing thermal insulation materials based on wool. The structural features and properties of wool fibers, as well as their influence on the formation of thermal insulation characteristics of nonwoven materials, are considered.

Special attention is given to the generalization and systematization of domestic and international studies in the field of needle-punched nonwoven materials produced from natural fibers. Existing technologies for nonwoven material formation are analyzed, and the influence of structural parameters on thermal insulation and physico-mechanical properties is established.

A comparative analysis of wool-based and synthetic thermal insulation materials is carried out, demonstrating the advantages of natural wool insulation materials in terms of environmental friendliness, hygroscopicity, and the ability to regulate heat and moisture exchange.

Based on the analysis of scientific and practical data, the necessity of investigating the influence of technological parameters, including punching frequency, number of layers, and the ratio of coarse to semi-coarse wool, on the structure formation and properties of multilayer nonwoven materials is substantiated. The main research directions are formulated, including the experimental investigation of the regularities governing the formation of the structure and properties of wool nonwoven materials and the evaluation of their thermal insulation characteristics.

Conclusions of Chapter 1

1. The analysis of the current state of wool raw material utilization demonstrated that sheep wool is a renewable natural resource with significant potential for the production of environmentally friendly thermal insulation materials. At the same time, substantial amounts of coarse wool generated from meat-fat sheep breeds are utilized inefficiently, which necessitates the development of new approaches for its processing.

2. The analysis of scientific literature showed that the morphological characteristics and properties of wool fibers provide high thermal insulation capability, moisture regulation, and air permeability, making wool a promising raw material for environmentally safe thermal insulation materials. In addition, the natural biodegradability of wool at the end of its life cycle contributes to the formation of closed-loop biological cycles and corresponds to the principles of the circular economy and sustainable development.

3. The analysis of nonwoven manufacturing technologies demonstrated that mechanical fiber bonding methods, particularly needle punching, are widely used for the production of wool-based thermal insulation materials. This technology ensures the formation of a strong three-dimensional structure through the mechanical

entanglement of fibers and enables the production of materials from natural wool without the use of chemical binders.

4. The investigation of existing wool-based thermal insulation materials showed that various product forms are available on the market, including rolls, mats (boards), and blown insulation materials. Rolled and board-type materials are the most widely used due to their ease of installation, practical applicability, and suitability for various building envelope structures.

5. A comparative analysis of wool-based and synthetic thermal insulation materials demonstrated that wool insulation possesses several competitive advantages, including environmental friendliness, renewability of raw materials, moisture regulation capability, and operational safety.

6. The analysis of factors determining the thermal insulation properties of nonwoven materials showed that thermal conductivity is primarily influenced by structural characteristics, including density, thickness, porosity, and fiber distribution. At the same time, the formation of the fibrous structure is significantly affected by technological process parameters.

7. Despite the large number of studies devoted to thermal insulation materials based on fibrous raw materials, the combined influence of needle-punching technological parameters, multilayer structure, and coarse wool content on the thermal insulation and operational properties of nonwoven materials remains insufficiently investigated. In addition, limited research has been devoted to the use of coarse wool from Kazakh sheep breeds for thermal insulation applications.

The second chapter of the dissertation presents a description of the raw materials, equipment, and technological scheme used for the formation of multilayer needle-punched nonwoven materials based on coarse and semi-coarse sheep wool. The technological sequence for producing the nonwoven materials is described in detail, including fiber preparation, web formation, and mechanical bonding by needle punching under industrial conditions. Parameters for the production of two-, three-, and four-layer nonwoven materials with different coarse wool contents using a two-stage needle-punching process (preliminary and main needle punching), with varying punching frequencies at the main stage, are presented. These parameters made it possible to investigate the influence of the number of layers, punching frequency, and fiber composition on the structural, thermal insulation, and physico-mechanical properties of the materials.

Experimental methods are presented, including the determination of thickness, surface density, warmth retention coefficient, air permeability, and tensile strength in accordance with standard testing methods. Optical microscopy and scanning electron microscopy (SEM) were used to analyze the structural features of wool fibers and the formed nonwoven materials.

Methods of statistical data processing and mathematical modeling are also described, including the application of response surface methodology (RSM) to evaluate the influence of technological parameters on material properties.

Conclusions of Chapter 2

1. Multilayer needle-punched nonwoven materials based on coarse and semi-coarse sheep wool subjected to standard primary processing were selected as the objects of investigation.

2. A technological scheme for the formation of wool nonwoven materials based on sequential stages of fiber preparation, fibrous web formation, and mechanical bonding by needle punching under industrial conditions was applied. The needle-punching process was carried out in two stages, preliminary and main, with variation of punching frequency at the main stage, which enabled the production of a series of experimental samples with different structural characteristics.

3. Two-, three-, and four-layer nonwoven materials with different punching frequencies and coarse wool contents were produced, enabling investigation of the influence of the number of layers, punching frequency, and coarse wool content on material properties.

4. Methods for determining thickness, surface density, warmth retention properties, air permeability, and tensile strength were substantiated and applied in accordance with international standards for characterizing the structure and properties of the obtained nonwoven materials.

5. Optical microscopy and SEM were used to analyze the morphological features of wool fibers and the structure of the formed nonwoven materials.

6. Statistical analysis and mathematical modeling methods, including response surface methodology (RSM), were applied to process experimental data and evaluate the influence of technological parameters on the properties of nonwoven materials.

The third chapter presents the results of comprehensive experimental investigations of the physico-mechanical and functional properties of multilayer needle-punched nonwoven materials based on coarse and semi-coarse sheep wool. Particular attention is paid to analyzing the influence of technological parameters involved in the formation of material structure, including the number of layers, coarse wool content, and needle-punching frequency, on the thermal insulation and performance characteristics of the materials.

The features of structural changes in the nonwoven materials resulting from variation in the number of layers are examined, along with their influence on thickness, surface density, strength characteristics, and air permeability. An analysis of the dependence of bulk fibrous structure formation on needle-punching technological regimes and wool blend composition was carried out.

Special attention is devoted to establishing regularities in tensile strength variation in both longitudinal and transverse directions, as well as to evaluating air permeability as an important parameter characterizing the thermal insulation properties of the materials. Statistical processing of experimental data was conducted, enabling identification of the significance of individual factors and their contribution to the formation of material properties.

The obtained results made it possible to establish the main regularities governing the formation of the structure and properties of multilayer wool nonwoven materials and to substantiate the role of structural parameters as the key factor determining their performance characteristics. Based on the conducted investigations,

practical conclusions and recommendations were formulated for regulating material properties through varying the number of layers and needle-punching parameters.

Conclusions of Chapter 3

1. An analysis of the influence of the number of layers, coarse wool content, and needle-punching frequency on the physico-mechanical and functional properties of wool nonwoven materials, including thickness, surface density, tensile strength, and air permeability, was carried out.

2. It was established that increasing the number of material layers leads to a gradual increase in sample thickness and surface density due to the formation of a more voluminous fibrous structure and an increase in material mass within the nonwoven web.

3. Tensile strength test results showed that the number of layers has a statistically significant influence on the strength characteristics of the material in both transverse and longitudinal directions ($P < 0.001$). The maximum tensile strength values were obtained for four-layer samples (393-481 N in the transverse direction and 390-446 N in the longitudinal direction). The coarse wool content and needle-punching frequency within the investigated ranges did not lead to statistically significant changes in strength, indicating the secondary influence of these factors.

4. The investigation of air permeability demonstrated that the primary factor affecting this parameter is the number of layers and, consequently, the material thickness ($F = 78.65$; $P < 0.001$). Increasing the number of layers leads to a decrease in air permeability due to increased density and fiber entanglement within the fibrous web. Variations in the ratio of coarse and semi-coarse wool and needle-punching frequency within the investigated ranges did not have a statistically significant effect on air permeability.

5. The key parameter determining the mechanical and barrier properties of wool nonwoven materials is the web structure formed by the number of layers. Fiber composition and needle-punching technological parameters within the investigated ranges exert a secondary influence.

The fourth chapter of the dissertation presents the results of experimental and analytical investigations of the thermal insulation properties of multilayer needle-punched nonwoven materials based on coarse and semi-coarse sheep wool. Particular attention is devoted to studying the influence of technological parameters involved in the formation of material structure, including coarse wool content, needle-punching frequency, and the number of layers, on the warmth retention coefficient.

The chapter examines the features of mathematical modeling of the thermal insulation properties of nonwoven materials using response surface methodology (RSM). A polynomial regression model describing the dependence of the thermal retention coefficient on the investigated factors is presented, along with the results of its statistical evaluation using analysis of variance (ANOVA).

The influence of each factor on the formation of the thermal insulation characteristics of the materials is analyzed in detail. Special attention is given to the structural features of multilayer nonwoven materials that determine their heat retention capability, as well as to the interaction of technological parameters during the formation of the fibrous structure.

Additionally, the results of factor interaction analysis are presented, including the combined influence of needle-punching frequency and number of layers, as well as three-factor interactions reflecting the complex nature of the formation of thermal insulation properties in wool nonwoven materials.

The final part of the chapter presents a generalized techno-economic assessment of the developed technology for producing nonwoven materials, taking into account raw material consumption and technological process parameters.

Conclusions of Chapter 4

1. A comprehensive assessment of the influence of coarse sheep wool content, needle-punching frequency, and number of layers on the thermal retention properties of the formed nonwoven materials was carried out. Mathematical modeling based on a full factorial experiment using response surface methodology (RSM) was applied for quantitative evaluation. Based on the experimental data, a polynomial regression model describing the dependence of the thermal retention coefficient on the investigated factors was developed. The model was found to be adequate and statistically significant based on analysis of variance (ANOVA) and residual analysis.

2. The analysis showed that all main factors (coarse wool content, needle-punching frequency, and number of layers) exert a statistically significant influence on warmth retention ($P < 0.001$), with the number of layers being the dominant factor providing the most substantial improvement in thermal insulation characteristics due to increased material thickness and reduced convective heat transfer.

3. Needle-punching frequency exerts an additional positive influence by forming a denser and more uniform fibrous structure that restricts air movement within the web. The influence of coarse wool content is less pronounced and is manifested mainly through interaction with other factors, confirming the complex nature of thermal insulation property formation.

4. Significant interaction coefficients between needle-punching frequency and number of layers, as well as a three-factor interaction among all investigated factors, were identified, indicating the necessity of considering the combined influence of technological parameters when optimizing the formation process of nonwoven materials.

5. The material structure determined by the number of layers and needle-punching density is the key factor governing the thermal retention properties of wool nonwoven materials, whereas coarse wool content plays a secondary yet interconnected role. This is associated with the fact that the investigated samples were produced from coarse and semi-coarse sheep wool characterized by similar chemical and physical composition.

6. According to the generalized techno-economic assessment of the technology, the resource intensity of the process was determined to be 1200-1300 KZT/m² and varied depending on the composition of the raw material blend. The technological process was shown to be economically feasible.

Conclusion

The dissertation research was devoted to the development and experimental substantiation of technological regimes for producing environmentally friendly multilayer nonwoven materials based on coarse and semi-coarse sheep wool for thermal insulation applications, as well as to identifying the regularities governing changes in the structure and key properties of nonwoven materials depending on technological parameters.

Based on the conducted investigations, the following main conclusions were formulated:

1. A systematic analysis of methods for manufacturing multilayer nonwoven materials and the properties of wool was carried out, and the key factors influencing the thermal insulation characteristics of insulation materials were identified. An experimental research program was developed using design of experiments methods. The selected factors included coarse wool content, needle-punching frequency, and number of layers.

2. Multilayer needle-punched nonwoven materials based on coarse and semi-coarse wool were manufactured under industrial conditions. The influence of the selected factors on material properties was experimentally investigated. The experiments involved variation in the number of layers (2-4), punching frequency (500-600 strokes/min), and the ratio of coarse to semi-coarse wool (40-60% coarse wool).

3. A statistically significant influence of the number of layers on the strength and air permeability of the materials was established. Increasing the number of layers from 2 to 4 resulted in an increase in material thickness from 5.38 mm to 9.98 mm, surface density from 658.5 g/m² to 1518.8 g/m², and tensile strength from 104 N to 481 N, while air permeability decreased from 2113.6 dm³/(m²s) to 819.8 dm³/(m²s). This behavior is explained by the increase in density and cohesion of the fibrous web structure. The influence of coarse and semi-coarse wool content and needle-punching frequency on strength properties and air permeability was found to be secondary, with no statistically significant effect identified within the investigated ranges.

4. The thermal retention properties of the materials were evaluated using response surface methodology (RSM). It was established that the number of layers makes the greatest contribution to thermal insulation performance, resulting in a significant increase in thermal retention regardless of fiber blend composition: increasing the number of layers from 2 to 4 led to an increase in the thermal retention coefficient by 44.5% for samples containing 40% coarse wool and by 33.6% for samples containing 60% coarse wool. Needle-punching frequency exerted an additional positive effect associated with increased material thickness and the formation of a denser fibrous structure, reducing convective heat transfer within the material. The influence of the coarse-to-semi-coarse wool ratio was mainly manifested through interaction with other parameters and was not independently statistically significant, which can be explained by the similar chemical and physical composition of the fibers used.

5. A polynomial regression model describing the dependence of the thermal retention coefficient on coarse wool content, needle-punching frequency, and number of layers was developed and verified for adequacy and statistical significance using

analysis of variance (ANOVA). The model enables prediction of the thermal insulation properties of the material within the investigated range of technological parameters.

6. Scientifically substantiated recommendations for technological regimes for manufacturing environmentally friendly multilayer nonwoven thermal insulation materials based on coarse and semi-coarse wool of Kazakh fat-tailed sheep breeds were developed. The recommendations are based on experimentally established regularities in the influence of the number of layers, needle-punching frequency, and wool composition on thermal retention, strength, and air permeability. The materials can be produced in the form of rolls or mats with adjustable thickness, density, and number of layers, enabling their application for thermal insulation in construction and technical fields. The manufacturing technology consisted of two stages: preliminary formation of individual layers at a punching frequency of 500 strokes/min, followed by layer consolidation at 600 strokes/min, at which optimal thermal retention, strength, and air permeability characteristics were achieved, ensuring the formation of a stable fibrous structure. The materials were produced in roll form, with semi-coarse wool layers positioned on the outer surfaces and coarse wool layers located in the inner layer.

Assessment of the completeness of the research objectives. The objectives formulated in the dissertation were fully accomplished on the basis of the conducted theoretical and experimental investigations. Data on wool as a raw material were systematized, fiber properties and methods for the formation of multilayer nonwoven materials were studied, experimental investigations were carried out, quantitative relationships between technological parameters and key material properties were established, and recommendations for technological regimes for manufacturing environmentally friendly thermal insulation materials were developed. The experimentally established regularities concerning the influence of the number of layers, needle-punching frequency, and the ratio of coarse to semi-coarse wool on thermal retention, strength, and air permeability, as well as the technological regimes developed on this basis, make it possible to improve the technology for producing environmentally friendly multilayer wool-based nonwoven thermal insulation materials.

Recommendations and initial data for practical application of the results. The obtained research results are recommended for use in the development and improvement of technologies for manufacturing environmentally friendly multilayer needle-punched wool-based thermal insulation materials for construction and technical applications.

Assessment of techno-economic efficiency of implementation. The proposed technological regimes make it possible to produce multilayer thermal insulation materials with adjustable thickness, density, and number of layers, as well as high thermal insulation efficiency and mechanical strength. The implementation of the developed technology facilitates the industrial utilization of coarse wool from Kazakh fat-tailed meat-fat sheep breeds, previously considered a low-demand by-product of animal husbandry, thereby reducing environmental impact and economic losses through the rational use of valuable raw materials and reduction of waste volumes.

Assessment of the scientific level of the research. The combined influence of needle-punching frequency, number of layers, and wool fiber composition on the formation of the structure of multilayer needle-punched nonwoven materials was investigated, and the regularities governing changes in warmth retention coefficient, tensile strength, and air permeability depending on these parameters were established. These findings represent a new scientific contribution to the field of wool-based thermal insulation materials. The value of the work lies in the approach to multilayer structure formation, consideration of interactions between technological factors, and the utilization of Kazakh coarse wool, which is currently underutilized and generally regarded as a by-product of animal husbandry.

The following publications have been published on the topic of the dissertation research:

1. Borkulakova Zh.K., Mels M.D., Shardarbek M.Sh., Bitus E.I., Sarybayeva E.E. Study on the strength of needle-punched nonwoven material made on the basis of sole trader “Miras” //The Journal of Almaty Technological University. – 2023. – Vol. (4). – P. 36-43. <https://doi.org/10.48184/2304-568X-2023-4-36-43>

2. Borkulakova Zh.K., Shardarbek M.Sh., Junisbekov M.Sh., Kuandykuly M. Specifics for manufacturing insulating needle-punched nonwoven materials from coarse wool //Proceedings of the 5th International Scientific Conference «Progress in Science» (February 22-23, 2024). – Brussels, Belgium, 2024. – P. 45-49.

3. Шардарбек М.Ш., Боркулакова Ж.К., Абзалбекулы Б., Кауымбаев Р.Т., Ташмухамедов Ф.Р., Сарыбаева Э.Е., Ораз Г.Т., Мажиханова Б.К. Анализ производства и свойства нетканых материалов: мировые тенденции и развитие в Казахстане //Механика и технологии. – 2024. – №3(85). – С.399-405. <https://doi.org/10.55956/FUMY4911>

4. Боркулакова Ж.К., Шардарбек М.Ш., Илхамова М.У. Особенности шерстяного волокна в качестве экологического нетканого изоляционного материала //Материалы международной научно-технической конференции «То‘qimachilik va yengil sanoatda ilmhajmdor innovatsion texnologiyalar va dolzarb muommolar yechimi (ТО‘QIMACHILIK VA YENGIL SANOAT – 2024)» Том 1. – Фергана: Ферганский политехнический институт, 2024. – 74-78 с.

5. Borkulakova Z., Shardarbek M., Ikhamova M., Orynbayev S., Abzalbekuly B., Sarybayeva E., Tashmukhamedov F., Kauymbaev R., Oraz G. Optimization of Warmth Retention in Nonwoven Materials Made from Coarse and Semi-Coarse Sheep Wool //Journal of Natural Fibers. – 2025. – Vol. 22(1). – P. 2578612. <https://doi.org/10.1080/15440478.2025.2578612>

6. Тулендиева Г.О., Шардарбек М.Ш., Гафуров Ж.К., Боркулакова Ж.К. Игерілмеген жүнді беймата материалдарына өңдеудің заманауи технологияларына шолу //Механика және технологиялар. – 2025. – №4(90). – Б. 252-259. <https://doi.org/10.55956/LRQJ3606>