Development of an algorithm for forming the structure of composite fiber insulation with heat-accumulating properties in clothing

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Abstract. In the article research results are presented, which aim to development of an algorithm for forming the structure of composite fiber insulation with heat-accumulating properties in clothing. The presence of heat-retaining polymer components in the structure of the fibrous composition of materials leads to its general heterogeneity. Combining such materials with traditional fibrous structures is a rather promising area, as it allows for the use of heat-retaining effect not only in thin materials, but also in voluminous thermal insulating materials. As the main core fibrous composition of materials used to study a system of combining with elements of heat-retaining components, we have selected composition of polyester fibers of various configurations and sizes. Pattern of connections between the composition of fibers and groups of materials intended for integrating with heat-retaining components, scheme for creating priority fibrous materials with heat-retaining properties, which form heat-protective textile clothing shells we have developed.

1. Introduction

Clothing heat-retaining properties are actively developing in all countries worldwide. They are of particular importance for cold-protective clothing. The presence of heat-retaining polymer components in the structure of the fibrous composition of materials leads to its general heterogeneity. This is the reason for the change in the properties of a composite material, as compared to the properties of its initial components. Special heat-retaining effects of materials are based on the phase-change properties of the integrated active polymers [1, 2]. Combining such materials with traditional fibrous structures is a rather promising area, as it allows for the use of heat-retaining effect not only in thin materials, but also in voluminous thermal insulating materials. For the purpose of a comprehensive analysis of the fibrous composition of modern textiles, we studied [3, 4] fiber classification according to [4]. Depending on their origin, textile fibers are divided into natural and chemical ones. Chemical fibers are subdivided into artificial and synthetic ones. Given the diversity of methods for obtaining primary fibers, modern
fibrous materials represent a wide range of products [5-7]. Therefore, an urgent task arises – development of an algorithm for forming the structure of composite fiber insulation with heat-accumulating properties in clothing.

2. Theoretical part
The range of natural and semi-natural insulating materials includes such fabrics as batting, sherston, and a loose variant of insulating material – feather-down mixture, which account for a much smaller share of industrial output in the total volume of the garment industry and, as a general rule, provide special properties of clothing based on the advantages of natural materials and on the absence or a small proportion of synthetic products in the clothing composition. This is important, for instance, in the production of clothing that protects against static electricity or children’s clothing. In this case, additional thermic regulation properties due to integrating heat-retaining materials into the structure of the clothing pack have some limitations. Therefore, as the main core fibrous composition of materials used to study a system of combining with elements of heat-retaining components, we have selected composition of polyester fibers of various configurations and sizes.

Our analysis of lining materials showed that their main parameters should ensure their high density with a small thickness, which provides the main important properties of the inner surface layer of clothing [8] – slipping and abrasion resistance.

This problem can be solved only at the stage of primary production of fabrics using initial composite fibers with heat-retaining properties, which are directly integrated into the material structure at the stage of primary nonwoven or knitted production.

Based on the research, we have developed a pattern of connections between the composition of fibers and groups of materials intended for integrating with heat-retaining components (Fig. 1).

![Diagram](image_url)

**Figure 1.** Block 1 “А” of the algorithm for creating the structure of composite fiber insulating materials: the connection pattern of the fibrous base and material groups of the closing heat-protective pack with heat-retaining materials

The considered fibers (in accordance with Fig.1) form the required functions in the corresponding layers of clothing.

Thus, in the corresponding material layers, different functions are provided:
M1 – the main barrier protection function against harmful environmental factors (production process and weather), preserving and maintaining the clothing shape and size;

M2 – the thermal insulation and thermoregulation function (including heat preserving);

M3 – moisture exchange, thermic regulation (including heat preserving), surface sliding.

Polymer materials with heat-retaining properties are classified based on the method of accumulating thermal energy, as well as the content of such components in the general structure of a composite material [9].

In the classification of heat-retaining materials, important characteristics of the thermal energy retaining process are as follows [10,11]:

• capacity per unit volume or weight;
• operating temperature range;
• methods of supply and extraction of heat and the corresponding temperature differences;
• temperature stratification in the accumulator;
• power required to supply and remove heat;
• volumes of structural elements related to the accumulation system;
• means for regulating heat losses by the heat accumulator;
• manufacturing and operating costs [11]

There is a classification of heat-retaining materials, as shown in Fig. 2 [11, 12].

For fibrous composite materials with heat-retaining properties, the clothing industry uses heat-retaining materials (HRMs), integrated with the structure and conditions of production and operation of their main fiber systems under consideration. Encapsulated and granular materials can be compatible with fibrous structures and depend on the fiber structure, size, and connection system. As solid hydrocarbons, we can use paraffin, ceresin, wax, primary higher fatty synthetic alcohols with obtaining the stabilization temperature of +53 to +80 °C [13]. This temperature range, as a prerequisite for application in clothing, is typical for clothing that protects against high temperatures. The study [10,14] is devoted to the development and research of cold-protective materials, which allowed to establish the actual melting point ranges for octadecane (C_{18}H_{36}), nonadecane (C_{19}H_{40}), eicosane (C_{20}H_{42}), the melting point of which is set within the range of +27.6...38.6 °C.

Among the substances and materials used as HRMs, we identified inorganic substances such as sodium thiosulfate pentahydrate (Na_{2}S_{2}O_{3}·5H_{2}O), sodium sulfate decahydrate (Na_{2}SO_{4}·10H_{2}O), sodium sulfite heptahydrate (Na_{2}SO_{3}·7H_{2}O), sodium carbonate decahydrate (Na_{2}CO_{3}·10H_{2}O), sodium acetate trihydrate (Na(CH_{3}COO)·3H_{2}O) [15], and typical paraffins [16,17].

However, the main temperature range of interest for heat accumulation in the operating mode of heat-protective clothing is within +20...+40°C [18].

3. Practical part
Our analysis of modern developments in the creation and application of special encapsulated materials with heat-retaining properties for fibrous structures allowed us to identify a group of materials intended for integrating with textiles for clothing.
For heat-protective clothing, as applicable to M3 material group, materials with heat-retaining properties can be integrated into the textile base using the method [19].

Based on this method, the most common types of textiles with heat-retaining properties have been developed, that are implemented in the form of nonwoven and knitted structures.

For voluminous heat-insulating materials of the M2 group in heat-protective clothing, it is advisable to concentrate micro-encapsulated components directly in the volume of fibers [20,21].

As a result, we obtained a variety of multicomponent fibrous integrated materials. Their basis consists of fibrous systems [22,23,24] that are typical for nonwoven voluminous textile materials, whereas integrated components are parts of heat-retaining micro-encapsulated materials of various sizes and proportions in volume.

Therefore, as a result of our studies of modern heat-retaining materials, their composition and production methods, as well as specifics of the method for integrating into textile materials, we developed a scheme for creating priority fibrous materials with heat-retaining properties, which form heat-protective textile clothing shells, as presented in Fig. 3.

Algorithm for forming the structure of composite fiber insulation with heat-accumulating properties in clothing has been developed (Fig. 4)
Figure 3. Block “B” of the algorithm for creating the structure of composite fibrous insulating materials: the scheme for creating priority fibrous materials with heat-retaining properties that form heat-protective textile clothing shells.

Figure 4. Algorithm for forming the structure of composite fiber insulation with heat-accumulating properties in clothing.
4. Discussion and conclusions
There is a concept and algorithm for designing complex textiles. Specific behavior of textiles is explored and resolved between methods of form-finding in physical studies, spring-based modeling and simulation, and finite element analysis. The sequence of methods is predicated upon the degree of topological complexity in the material system [25]. However, such a system and such an algorithm do not allow us to solve the problem of creating a fiber insulation. In the work [26] investigated the relationships between the thermal insulation properties of the set of materials and the parameters of the particular components of sets, as well as the configuration of layers. The results obtained [26] have expanded the knowledge about the thermal properties of complex fibrous materials, but do not have a comprehensive algorithm for designing new materials.

The result is the suggested algorithm that allows to build the route for obtaining a multicomponent insulating material depending on the type and structure of the core insulating materials. The algorithm allows to immediately determine the type of process methods for producing a new multicomponent material, depending on the chemical nature of obtaining heat-retaining active components, that are integrated into new composite clothing materials.

5. Acknowledgements
The reported study was funded by RFBR, project number 19-38-90324.

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