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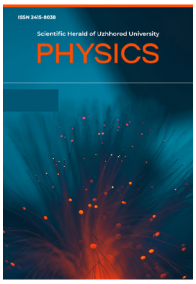

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Examination of the influence of hydrothermal treatment of textile materials on their physical and mechanical properties and development of innovative technology

Salikh Tashpulatov*
Doctor of Technical Sciences, Professor
Tashkent Institute of Textile and Light Industry
100059, 5 Shohjahon Str., Tashkent, Uzbekistan
Jizzakh Polytechnic Institute
130100, 4 I. Karimov Str., Jizzakh, Uzbekistan
https://orcid.org/0000-0001-5483-2644

Dilrabo Bakhriddinova
PhD in Technical Sciences, Associate Professor
Tashkent Textile and Light Industry Institute
100059, 5 Shohjahon Str., Tashkent, Uzbekistan
https://orcid.org/0000-0003-2083-4902

Shakhlo Nutfullaeva
Postgraduate Student
Bukhara Engineering Technological Institute
200100, 15 Q. Murtazaev Str., Bukhara, Uzbekistan
https://orcid.org/0009-0001-8739-4705

Lobar Nutfullaeva
PhD in Technical Sciences, Associate Professor
Bukhara Engineering Technological Institute
200100, 15 Q. Murtazaev Str., Bukhara, Uzbekistan
https://orcid.org/0000-0001-6982-3185

Mukhlisa Muminova
Master, Assistant
Bukhara Engineering Technological Institute
200100, 15 Q. Murtazaev Str., Bukhara, Uzbekistan
https://orcid.org/0009-0003-8299-9662

Abstract

Relevance. Investigation in the field of textile materials and the effect of processing on their properties, is relevant, as it helps to develop more effective processing methods and increase the resistance of textile materials to the influence of various factors, which is important for both manufacturers and consumers.

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*Corresponding author

Purpose. The purpose of the study was to examine the effect of hydrothermal processing of textile materials on their physical and mechanical properties, develop a technology for the production of clothing using a new method (device) of press equipment for hydrothermal processing of composite material.

Methodology. The analysis method was used during the study, and an experiment was also conducted in which the temperature of the steam that did not fall below 160°C was used when processing the selected fabric samples, and the temperature of the working bodies of the press for forming the back was at least 110°C.

Results. As a result, the influence of hydrothermal treatment on the properties of textile materials was examined in detail and established. Having analysed the existing method of hydrothermal treatment using a vacuum unit, it was established that the conventional method of treatment leads to a substantial decrease in fabric thickness, breaking load and air permeability. It was also noted that during the hydrothermal treatment of the material, it is exposed under the influence of pressure. This leads to densification and flattening of the threads inside the material, creating flat areas, which causes adverse changes in the physical and mechanical characteristics of the fabric.

Conclusions. These factors indicate a potential deterioration in the quality and durability of textile products, which can increase the percentage of defects and negatively affect consumer satisfaction. This study also points to the prospects of using a vacuum installation in hydrothermal treatment, which allows preserving the desired properties of materials, improving the quality of the final products. The practical importance of the results of this study lies in the possibility of improving the quality of textile products and reducing the damage to materials, which is important for ensuring longer operation of textile products and increasing consumer satisfaction.

Keywords: atom; moulding of products; fabric structure; fibre deformation; vacuum installation; breaking load; breathability

Introduction

The textile industry is one of the modern world's most dynamically developing and important production areas. Textile materials are used in various fields, ranging from the fashion industry to medical applications. However, to meet the ever-growing demand for textile products, manufacturers face constant challenges in the quality and performance of materials.

Hydrothermal (wet-heat) treatment of textile materials is an effective method that allows improving and optimising the properties of these materials substantially. This includes reducing the material consumption, metal and energy consumption in production, increasing product strength, durability, and reliability. Consequently, such technologies contribute to reducing the weight and cost of structures, which makes them more competitive in the market. In addition, hydrothermal treatment increases technological productivity while maintaining the flexibility and versatility of the process. These factors are important for the textile industry, as they improve product quality and make production more efficient.

The improvement of technology and equipment for wet-heat treatment (WHT) is an urgent task in the textile industry. It is based on the use of moulding properties of various materials, such as fabric, nonwovens, leather, fur, knitwear. This approach allows achieving a high degree of stability in the configuration of clothing parts, which in turn contributes to improving the quality and durability of textiles, reducing the number of seams and improving overall production efficiency.

According to S. Samieva *et al.* [1], hydrothermal treatment is a complex process that affects many physical and mechanical properties of textile materials. In particular, this process can cause changes in the thickness of the fabric, breathability, and other characteristics of the material. The greatest attention was paid to optimising the parameters of hydrothermal treatment to ensure the preservation or even improvement of the quality of textiles.

S. Mahkamova *et al.* [2] state that hydrothermal treatment by repeated washing of textile materials can have both positive and negative effects on the basic properties of the material, depending on the conditions of use. It was emphasised that properly configured parameters of hydrothermal treatment can strengthen some textile product characteristics, such as durability and elasticity. Therewith, uncontrolled or excessive processing can cause undesirable changes in the structure of the material, which will negatively affect its quality and durability.

S. Makhkamova & Z. Valieva [3] in their study drew attention to the importance of finding optimal conditions for hydrothermal treatment that will maximise the potential of this process and minimise its negative consequences. In the study, the work on the selection of optimal parameters to preserve the physico-mechanical properties of textile materials during hydrothermal treatment by washing was conducted [3].

According to a study by D. Kurbanov [4], hydrothermal treatment of textile materials can have a substantial impact on their physical and mechanical properties. The researcher drew attention to the fact that this process can change the material's structure, leading to its more compact organisation. This, in turn, can lead to an improvement in some characteristics, such as strength and resistance to wear.

However, in the study by N. Murodova [5] also noted that improper hydrothermal treatment, namely multiple washes or the use of uncontrolled parameters, can cause the opposite effect. In particular, excessive exposure to moisture and heat can lead to deformation and loss of material properties. This study also emphasised the importance of careful monitoring and adjustment of hydrothermal treatment conditions to achieve the desired results and minimise negative consequences.

Since the studies mentioned above did not pay due attention to the improvement of the hydrothermal treatment process, this study aimed to develop a new clothing production method. This method involves using a vacuum installation, which can contribute to the preservation or improvement of the physical and mechanical properties of materials.

Materials and Methods

The study was conducted at the company "Maxpress Industry" (Uzbekistan). The materials used during the study included woollen fabrics for men's jackets designed for autumn, for seasonal and summer – polyester and viscose fabrics. Adhesive materials that have a textile base were used to ensure the preservation of the shape of various parts of clothing, such as, for example, backs. These materials are presented by various companies, such as HYMO from Japan, Kufner from Germany, Iskoj from Russia, DANELLI from China, and Camela from Poland.

In the course of the study, the hydrothermal treatment process was conducted on a special vacuum forming device developed using a polymer composition instead of adhesive gasket materials (Fig. 1-3, Table 1).

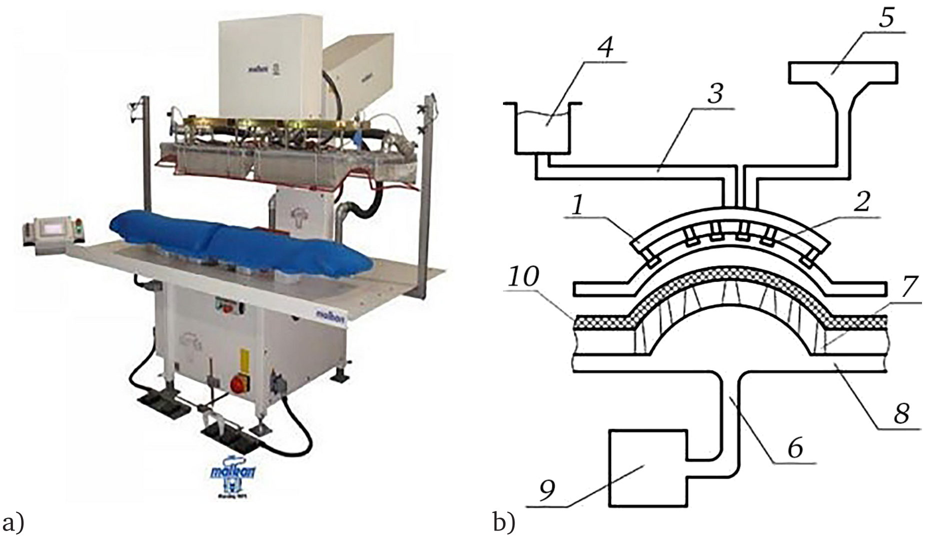
Figure 1. General view of the bottom cushion of the vacuum installation made of composite material
Source: compiled by the authors

Table 1. Technical characteristics of the bottom cushion of the vacuum installation

No.	Technical specifications	
1	Length, mm	A-700; B-580
	Width, mm	A-330; B-440
	Height, mm	A-73; B-53; B-95
	Wall thickness, mm	6
	Weight, kg	3.7
2	Thermal resistance, °C	325
3	Mechanical resistance, MPa	34
4	Material of the working body	composite material

Source: compiled by the authors

The improvement of the technological scheme was conducted based on investigating the mechanism of surface formation of both flat and volumetric sections of the back of clothing and methods of fixing them. Experiments were conducted on a press to form the back of the brand UPP1617KI, manufactured by the German company "Malkan", to develop an improved technology that gives the details of clothing shape stability using a vacuum installation.



a) b)

Figure 2. Press for processing the back of a men's jacket UPP1617KI (Malkan) with a bottom cushion of a vacuum installation

Note: a) appearance; b) block diagram of the equipment: 1 – upper cushion, 2 – nozzles for PC and warm air supply, 3 – pipeline, 4 – PC container, 5 – hair dryer, 6 – vacuum chamber, 7 – perforation, 8 – lower cushion, 9 – compressor, 10 – semi-finished product (processed fabric)

Source: compiled by the authors

Figure 3. The process of testing the method of shaping in the production conditions of "Maxpress Industry"

Source: compiled by the authors

When processing semi-finished products, the surface temperature of the working bodies was maintained at least 110°C and the temperature of the steam used for processing was at least 160°C, the back of the semi-finished product was placed on the lower working bodies of the press in accordance with the established procedure. Then, the deformation of the back of the product was conducted through a press, and then drying and stabilisation of a given shape were conducted.

Experiments were conducted with various fabric samples, as indicated in Table 2, to estimate the diameters of the inlet holes that should be created in the lower cushion of the device. The fabric samples had dimensions of 250×50 mm and were secured with clips in accordance with the "strip" technique. Uniaxial stretching of materials was conducted on a special breaking machine Autograph AG-1 (Shimadzu, Japan).

Table 2. Characteristics of costume fabrics

No.	Name of the fabric	Surface density g/m^2	Fibrous composition, %	Mechanical characteristics			
				Breaking load, N		Breaking elongation, %	
				Base	Warp and weft	Base	Warp and weft
1	Tweed (Art. 89-05)	374.4	10% wool 20% 70% PE	970	680	19	9
2	Corduroy (Art.06535)	250.5	35% 65% PE	1010	755	18	9
3	Costume “Euro” (Art.180703)	315.9	20% 80% PE	750	550	21	14
4	Christmas tree “Spruce” (Art. 11684)	164.7	20% viscose 80% PE	739	608	20	14
5	Diagonal Blue (Art.VT-468)	173.9	90% PE 10% viscose	898	709	22	12

Source: compiled by the authors

The calculation of pressure losses caused by local resistances was conducted using the Weisbach equation (1):

$$h_m = \zeta(v^2/2g) = \zeta h_v, \tag{1}$$

where: $h_v = v^2/2g$ – the high-speed pressure.

The pressure losses were calculated using the Borda formula, which was derived from the equations of D. Bernoulli and the law of conservation of momentum (2):

$$h_m = [(1/(\varepsilon - 1)]^2(v_2^2)/2g) = \zeta(v_2^2)/2g), \tag{2}$$

where: $\zeta = \left(\frac{1}{\varepsilon} - 1\right)^2$ – the coefficient of resistance, in relation to speed (in a section of a narrow section of the pipeline); $\varepsilon = F_c/F_2$ – compression ratio, determined by the ratio of the area of the compressed section F_c to the area of the pipe in the section F_2.

The compression ratio during operation was calculated using the formula proposed by A.D. Altshul (3):

$$\varepsilon = 0.57 + [0.043/(1.1\text{-}n)], \tag{3}$$

where: $n = F_2/F_1$ – the ratio of pipe areas in narrow and wide sections.

The value of the local resistance coefficient was determined by the formula (4):

$$\varepsilon_{\text{conf}} = C_c\zeta = C_c\left(\frac{1}{\varepsilon} - 1\right)^2, \tag{4}$$

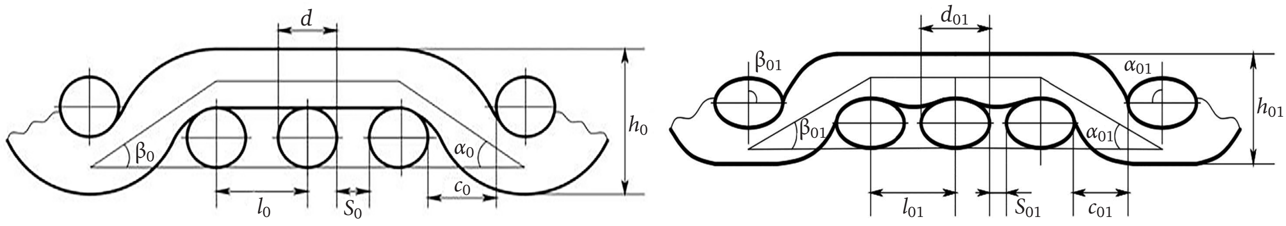
where: C_c – the compression ratio.

Using the analysis method, the results of experiments in laboratory conditions were also evaluated to determine the degree of influence of pressure and humidity on the properties of textile materials. This analysis allowed understanding what changes occur in the properties of the material under such influences. As part of the theoretical part of the study, this method was used to analyse the physical and mechanical properties of the material before and after wet-heat treatment and to examine the material’s abrasion resistance. It allowed identifying changes in the properties of the material caused by the technological process of the WHT and drawing conclusions about its impact on textiles.

Using the statistical method in this study, various indicators of the properties of textile materials were compared before and after wet-heat treatment. This method allowed assessing the degree of changes in the thickness of the fabric, breaking load, breathability, and abrasion resistance and to make a statistically substantial comparison between the samples of the material before and after the WHT.

Results

According to the current technology, mechanical pressure, superheated process steam, and a certain temperature for a certain time are used to achieve a given shape of textile-made clothing parts. As a result of the influence of these factors on a semi-finished textile material, its structure changes, which leads to a deterioration of its properties. This, in turn, leads to a decrease in the overall quality of the final clothing. For example, when forming a mould using mechanical pressure, the threads that make up the textile material are subjected to undesirable loads that lead to microscopic damage (Fig. 4-6).

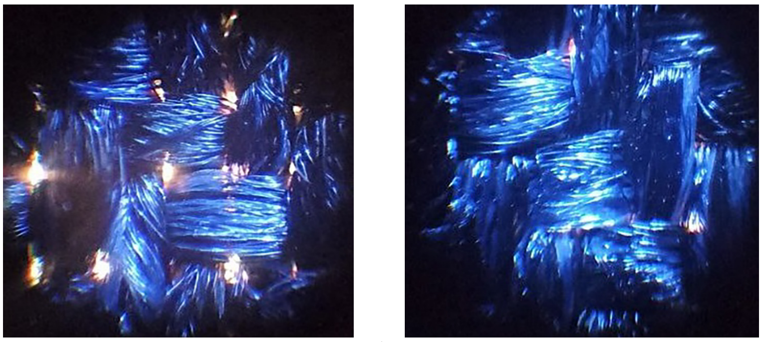


a) b)

Figure 4. Scheme of changing the cross-section of fabric threads before (a) and after (b) hydrothermal treatment (WHT)

Note: d – the initial diameter of the thread and d_{01} – after the WHT; h_0 – the initial thickness and h_{01} – after the WHT; l_0 – the initial distance between the axes of the threads and l_{01} – after the WHT; S_0 – the distance between the edges of the threads and S_{01} – after the WHT; c_0 – the distance between the threads where the thread bends in the phase of passage and c_{01} – after the WHT; α_0, β_0 – axial tilt angles of the thread in the passage phase and α_{01}, β_{01} – after the WHT

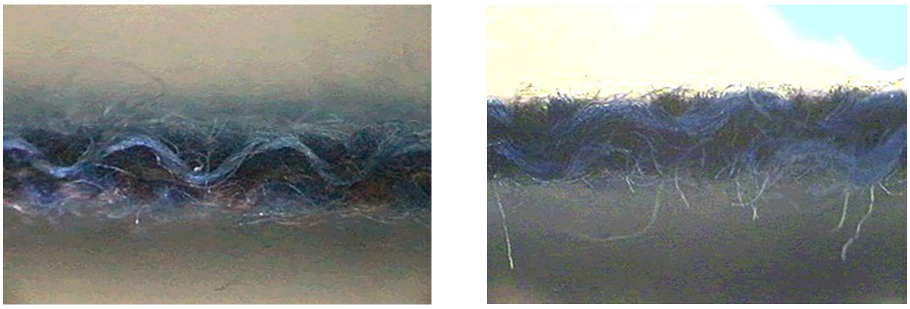
Source: compiled by the authors



a) b)

Figure 5. Micrograph of textile material before (a) and after (b) the WHT

Source: compiled by the authors

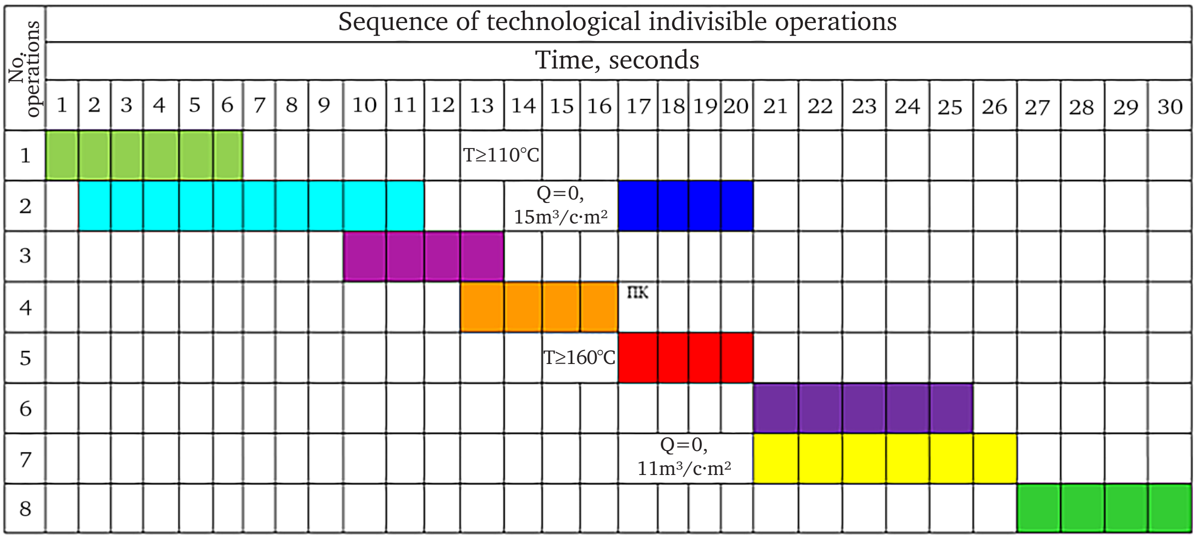


a) b)

Figure 6. Micrographs of the fabric section before (a) and after (b) pressing and WHT

Source: compiled by the authors

As a result of such damages, the original physical, mechanical, hygienic, and geometric characteristics of the material are violated. These characteristics may include thickness, density, breaking load, breaking elongation, stiffness, breathability, vapour permeability. Such changes in the material can negatively affect its quality and ability to perform its functional tasks. For example, this can lead to a decrease in strength, increased breathability or loss of hygiene of textile products [6, 7]. The above-mentioned WHT method showed the need for technology development to improve the quality of the product and the stability of the clothing part, reduce the damage to the structure of the textile material of the product part by using a fundamentally new working body of technological equipment. The cyclogram of the work of the press UPP1617KI of the company “Malkan” in combination with steaming and pressing is shown in Figure 7, which also describes the technological process of WHT and shaping. The temperature of the working surface of the pillows should be maintained at the level of $Tw \geq 110°C$.



No. operations	Sequence of technological indivisible operations																													
	Time, seconds																													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	🟩	🟩	🟩	🟩	🟩	🟩							T≥110°C																	
2		🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦			Q=0, 15m^3/c·m^2			🟦	🟦	🟦	🟦										
3										🟪	🟪	🟪	🟪																	
4													🟧	🟧	🟧	🟧	ПК													
5															T≥160°C		🟥	🟥	🟥	🟥										
6																					🟪	🟪	🟪	🟪	🟪					
7																	Q=0, 11m^3/c·m^2				🟨	🟨	🟨	🟨	🟨	🟨				
8																											🟩	🟩	🟩	🟩

Figure 7. The cyclogram of control and operation of automated equipment of the ironing vacuum installation of the WHT for the formation and fixing of the shape of the part of the back of a man's jacket

Note: 1 – preparation and laying of the product on the bottom cushion ($T_{bot.} \geq 110$°C; 2 – switching on vacuum-suction ($Q = 0.15$ m^3/(cm^2) in the lower cushion and the formation of a shape by deforming the mesh structure of the fabric of the part; 3 – lowering the upper cushion and stopping within 2-3 cm of the semi-finished product; 4 – applying a polymer composition to the specified areas of the deformed part; 5 – steaming with superheated steam at a temperature of 1600°C using the upper cushion over the entire surface of the part with the vacuum suction turned on (Q = 0.15 m^3/(cm^2) until the end of the technological process; 6 – lifting the upper cushion and returning to its original position; 7 – stabilisation and drying of a given shape by vacuum suction through the lower cushion with parameters Q = 0.11^{m3}/(cm^2); 8 – removal of the semi-finished product

Source: compiled by the authors

The semi-finished product is placed on the bottom cushion along the upper and lower points of the backrest line. A semi-finished part is placed on the lower forming cushion. Then, vacuum deformation of the part is conducted through the lower pillow, and the upper pillow is lowered and stopped before reaching 2-3 cm to the semi-finished product. Then, a polymer composition is applied to the specified local areas, and after the end, superheated steam is applied through the upper cushion. After that, the upper pillow is lifted and returned to its original position, then stabilisation and drying of the given shape by vacuum suction through the lower pillow and removal of the semi-finished product. The process of vacuuming in a limited technological volume in the lower cushion consists in reducing the air (gas) pressure to values below atmospheric, as described in L. Nutfullaeva *et al.* [8].

The level of gas rarefaction is determined by the ratio of the average free path $\bar{\lambda}$, which is associated with mutual collisions of gas molecules in a given medium. Depending on this ratio, vacuum degrees are distinguished, such as ultra-high (when $\bar{\lambda}$, substantially larger than the particle size r), high (when $\bar{\lambda}$, larger than the particle size, but not by much), medium (when $\bar{\lambda}$, approximately equal to the particle size), and low (when $\bar{\lambda}$, substantially smaller than the particle size). The average length $\bar{\lambda}$, over which molecules can move freely, given the variety of their velocities during mutual collisions, is defined as (5):

$$\bar{\lambda} = \frac{1}{\sqrt{2} n_o \delta}, \tag{5}$$

where: n_o –number of molecules (in cm^3); δ – cross-section for the interaction of molecules.

In the collision of particles formed by molecules with $d \approx 10^{-8}$ cm, the determination of δ is conducted by (6):

$$\delta = \pi d^2. \tag{6}$$

To analyse the efficiency of a vacuum installation, it is important to have information about the characteristics of different vacuum levels (Table 3). It is necessary to analyse the average free path of $\bar{\lambda}$ air molecules (1) and analyse it by comparing it with the dimensions of clothing elements to determine what level of vacuum is necessary for the formation of clothing parts. In the case of a vacuum level, n_o in 1 m^3 is in the range from 10^{22} to 10^{19}, the average free path length $\bar{\lambda}$ is in the range from 0.00225 to 2.25 m. This value is comparable to (*r*) of the installation for creating a vacuum for the purpose of forming clothing parts, that is, at an average vacuum level $\bar{\lambda}$ less than or approximately equal to the size of the device ($\lambda \leq r$).

Table 3. Parameters of different vacuum levels

Characteristics	Vacuum level			
	Low	Medium	High	Ultra-high
Pressure (mmHg)	760-1	$1\text{-}10^{-3}$	$10^{-3}\text{-}10^{-7}$	Less than 10^{-8}
Number of molecules n_o, m^3	$10^{25}\text{-}10^{22}$	$10^{22}\text{-}10^{19}$	$10^{19}\text{-}10^{13}$	Less than 10^{13}
Dependence of the coefficients of thermal conductivity and internal friction	There is no dependency	The dependency is calculated based on $\bar{\lambda}/D$	Direct dependence on pressure	Practically absent

Source: compiled by the authors

Many holes are provided in the lower cushion of the installation to create the shape of clothing parts using vacuuming. These holes can have various shapes, which are selected considering the air dynamics and the need to provide the best conditions for fabric deformation [9]. Therefore, to create a vacuum in a closed technological space limited by the contour of the lower cushion, it is necessary to maintain the pressure at the level of $p = 1 - 10^{-3}$ mmHg, which corresponds to the average vacuum level. Vacuuming is achieved by removing air from a closed, sealed space using a vacuum pump. In this device, air jets pass through holes of different shapes (Fig. 8): they can taper to the lower surface like conical confusers (Fig. 8a), expand to the lower surface (Fig. 8b) or have a cylindrical shape (Fig. 8c).The movement of air jets or other gases through such holes is calculated according to the principles of hydrodynamics.

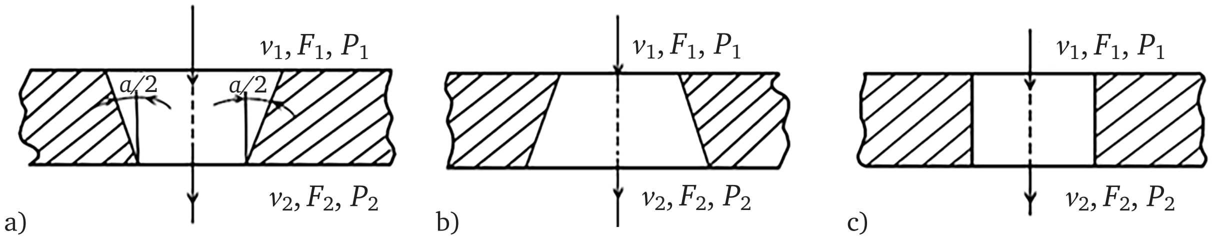


Figure 8. Types of perforations and their effect on aerodynamic parameters

Note: v – air velocity; F – cross-sectional area; p – pressure

Source: compiled by the authors

In most cases, the small changes in the basic physical properties of air and gases encountered in technology, such as density, viscosity, and temperature, when moving at low speeds and pressures (close to atmospheric), are so insubstantial that they can be neglected. This allows applying the basic principles of hydrodynamics to the analysis of aerodynamic processes [10].

A real liquid has a viscosity, and therefore, substantial resistance forces arise, including both internal and external friction. These forces lead to irreversible losses of pressure energy. Such losses are usually called linear pressure losses (h_{tr}). In addition, there are pressure losses on local resistances (h_m), which arise due to the specific features of geometry, design, and technology of moving or transporting a liquid or gas flow. Based on this, losses on any of the taken sites are defined as (7):

$$h_{nom} = h_{mp} + h_m. \tag{7}$$

When analysing energy losses in the movement of a liquid or gas, the impact of local resistances, which are caused by several factors, is considered. First, a change in the cross-section, including extensions and constrictions, substantially affects the flow. In addition, the curvature of the air channels, such as the flow turns, contributes to energy losses. Branching and merging of streams can also provide additional resistance to movement. Especially important in aerodynamic calculations is the consideration of local resistances, which are associated with the design features of the system [11].

The calculation of pressure losses caused by local resistances is conducted using the Weisbach equation (1) or by determining through the pressure loss Δp_m (kgf/m^2) in the local resistance (8):

$$\Delta p_m = (\gamma v^2/2g), \tag{8}$$

where: ζ – the coefficient measured in experiments and embodies the loss of pressure as a percentage of the velocity pressure.

In the case of a sharp narrowing of the duct, the air flow is compressed first, and then its expansion. The main pressure losses with such a narrowing occur in the expansion area. Table 4 contains the values of ζ depending on the ratio of the areas n between the narrow section and the wide section F_2 of the F_1 pipe.

Table 4. Values of ζ depending on *n*

$n = F_2/F_1$	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	1
Z	0.41	0.4	0.38	0.36	0.34	0.3	0.23	0.2	0.16	0

Source: compiled by the authors

The change in the rate of flow during compression occurs in the case of a gradual narrowing of the pipeline, which is called a confuser, as shown in Figure 9. The coefficient ζ for the confuser is calculated also considering the coefficient C_c (4). The value of the correction factor C_c depends on the taper angle α of the confuser. When conducting aerodynamic calculations, a graph showing the dependence of C_c on α can be used.

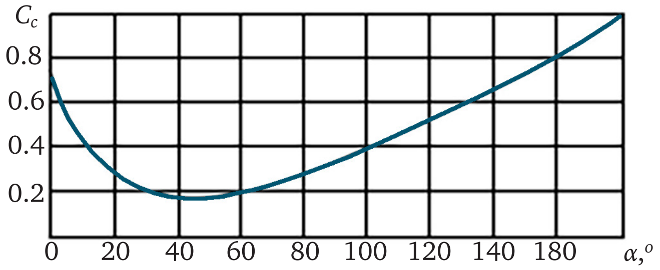


Figure 9. The dependence of the corrective compression ratio C_c on the taper angle
Source: compiled by the authors

With an increase in the velocity in the confuser, some transformation of the pressure in the flow into kinetic energy occurs.

The pressure loss due to a sudden expansion of the flow is also calculated using the Borda formula (9):

$$h_m = \zeta(v_1^2)/2g), \tag{9}$$

where: $\zeta = (1 - V_2)/V_1)^2$; $v_1^2/2g$ – pressure in a narrow section.

Also, the coefficient of local resistance ζ can be expressed as follows:

$$\zeta = \left(1 - \frac{F_1}{F_2}\right)^2 = \left[1 - \left(\frac{d_1}{d_2}\right)^2\right]. \tag{10}$$

In the case of the expression of the coefficient ζ relative to the velocity head (in a wide section), the following is obtained (11):

$$h_m = \left(\frac{V_1}{V_2} - 1\right)^2 (v_2^2/2g) = \left(\frac{F_2}{F_1} - 1\right)^2 (v_2^2/2g). \tag{11}$$

When analysing the pressure loss resulting from the resistances in the diffuser, a special correction factor known as the softening factor (C_m) is considered. The value of this coefficient depends on the angle of expansion (α) of the diffuser (Table 5).

In the diffuser, some part of the kinetic energy is converted into pressure energy. A general formula is used that considers the local resistance coefficient (ζ) to calculate the pressure loss associated with local resistances in the diffuser, considering the softening coefficient (C_m) (12):

$$h_m = C_m[(v_1 - v_2)^2/2g]. \tag{12}$$

Table 5. Values of the softening coefficient C_m depending on the opening angle α

α,°	C_m
8	0.16
15	0.35
30	0.8
60	0.95

Source: compiled by the authors

When analysing the aerodynamics of the passage of air through various configurations of holes, it becomes evident that a smooth narrowing of the cross-section from the inlet to the outlet, made in the form of a confuser in the lower part of the material forming device, is preferable. This is explained by the fact that in the process of creating a vacuum in the technological space, the air is sucked from a larger section (the upper part of the perforation) to a smaller section (the lower part of the perforation). According to the equation of D. Bernoulli and the mass conservation equation ($Q = V_1{*}F_1 = V_2{*}F_2 = \text{const}$), when a liquid (or gas) moves in a horizontal pipe with different sections, the velocity of the liquid is higher in the narrowing areas, and the pressure is higher in wider areas where the velocity is lower.

Thus, positioning the deformable fabric in accordance with Figure 10 brings great benefits: it provides a tighter fit to the lower surface of the device since it increases the area that is exposed to atmospheric pressure during vacuuming; it also creates a pressure difference between the upper and lower parts of the pillow, and the hole in the lower part has a smaller diameter. This distribution of contact between the fabric and the working surface of the pillow contributes to a more efficient fabric moulding process, making it more favourable and intensive.

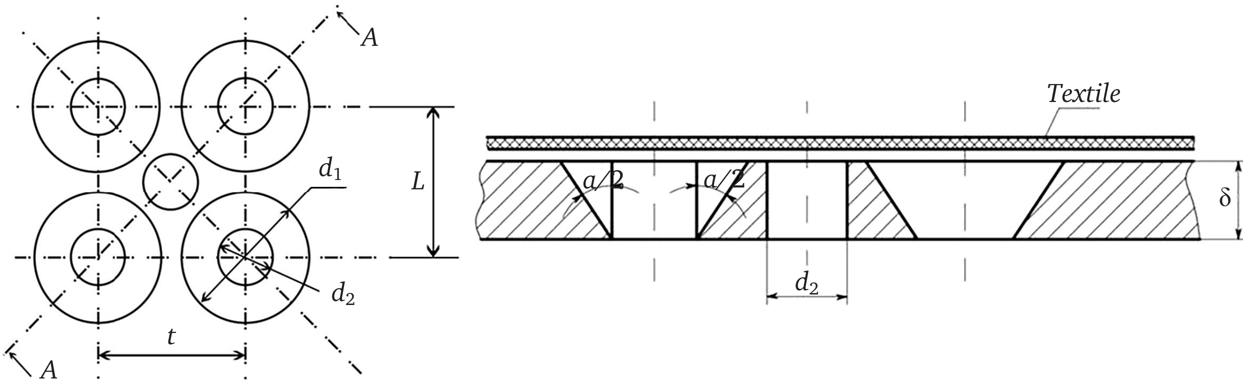


Figure 10. An elementary cell containing holes inside the thickness δ in the lower cushion of the device for forming three-dimensional parts of clothing using the vacuum method

Note: α – taper angle; *t* – distance between the perforations; d_1, d_2 – diameters of the inlet and outlet holes, respectively

Source: compiled by the authors

Since air is considered a compressible fluid in this context, the equation of D. Bernoulli, used for the flow of an ideal liquid, can be successfully used in the case of any gas flow with minor pressure changes [12]. In particular, with small differences in temperature between the transported air and the environment, it is possible to consider the difference in geometric altitude levels, and the equation of D. Bernoulli can be represented as (13):

$$\frac{P_1}{\gamma}+\frac{V_1^2}{2g}=\frac{P_2}{\gamma}+\frac{V_2^2}{2g}=\text{const, m.} \qquad (13)$$

Which can also be presented in a more convenient form for calculations (14):

$$p_1+\frac{\gamma V_1^2}{2g}=p_2+\frac{\gamma v_2^2}{2g}=\text{const, kgf/m}^2. \qquad (14)$$

For real gases, an additional term is added to equation (14), which considers the pressure losses Δp, associated with overcoming hydraulic resistances (3). Thus, if the pressure is measured in Pascals, equation (14) changes as follows (15):

$$p_1+\frac{\gamma v_1^2}{2}=p_2+\frac{\gamma v_2^2}{2}+\Delta p, \qquad (15)$$

where: v_1, p_1 – velocity and pressure of the gas (in the initial part); v_2, p_2 – velocity and pressure at the outlet of the pipeline; γ – volume weight or density of a gas, measured in kg/m^3.

In aerodynamic calculations for ordinary air, a standard value of γ is often used, equal to 1.2 kg/m^3. For a gas pipeline of any configuration, the pressure loss due to friction ($\Delta p = \Delta p_f$) over a section of length l can be calculated using the Darcy formula, applied to circular sections (16):

$$\Delta p_f=\frac{\lambda}{d}*\frac{\gamma V^2}{2}*l,\text{ Pa}, \qquad (16)$$

where: λ – coefficient describing the friction pressure loss along the section of length *l*; *d* – diameter of the duct, m.

For approximate calculations, a value of λ equal to 0.02 can be used. According to equation (3), it can be argued that the loss of friction pressure is proportional to the length of the duct (and the thickness of the bottom cushion). It is important to consider that the pressure losses caused by friction are inversely proportional to the size of the hole. In addition, Δp increases non-linearly as the air velocity increases, having a parabolic dependence. Thin-sheet steel was used for most of the ducts, and its absolute roughness is $k = 0.1$ mm.

However, if the ducts are made of other materials, then to account for changes in the specific resistance to friction C_f and λ/d, it is necessary to introduce a correction factor β (17):

$$\beta=(kV)^{0.25}, \qquad (17)$$

where: k – roughness value of the inner surface of the duct, mm; V – air velocity, m/s.

Based on the physical and mechanical properties of the fabric used to form the parts of clothing, it is possible to pre-estimate the diameters of the inlet holes that should be created in the lower cushion of the device. As can be seen from the data presented in Table 2, the average values of the maximum load required for the rupture of the considered fabrics along the base and weft are 873/660 N, respectively. Therefore, the specific tearing load R_t, expressed in newtons for each millimetre of the length of the material, is equal to 17.5/13.2 N/mm on the basis/weft, respectively. The maximum tearing load (R_{st}), considering the circumference (πd), will be equal to the average specific tearing load (18):

$$R_{st} = R_t{}^*\pi d, \text{N}. \quad (18)$$

The ultimate tensile stress σ_{st} at which fabric destruction occurs is defined as (19):

$$\sigma_{st} = \frac{R_{st}}{F}, \text{N/mm}^2, \quad (19)$$

where: $F = \pi/4$ – size of the hole; d – diameter, mm.

Given (18), the following is obtained (20):

$$\sigma_{st} = \frac{R_t * \pi d * 4}{\pi / d^2} = \frac{R_t * 4}{d}, \quad (20)$$

therefore (21):

$$d = \frac{4 * R_t}{\sigma_{st}} \text{ mm}. \quad (21)$$

For average stress parameters at break (26.55 N/mm^2) and specific breaking loads both on the base and on the weft (15.36 N/mm^2), the minimum diameter of the inlet is (22):

$$d = \frac{4 * 15.36}{26.55} = 2.3 \text{ (mm)}. \quad (22)$$

Therefore, when creating perforations in the form of a confuser, it is established that the diameter of the outlet is 2 mm, and the upper hole is 4 mm (considering technical requirements). It is necessary to compare the surface dimensions necessary to create an element of clothing with the interval between the holes (t) to determine the number of such perforations located in the unit cell. For this purpose, a structurally set pitch of 6 mm is assumed, which allows placing an additional hole d_2 with a diameter of 2 mm in the centre of this cell.

It is possible to make an approximate calculation of the loss of air pressure, which is sucked through the perforations, using the described system. For a specific example, hole sizes such as 4 and 2 mm will be assumed. The depth of the holes corresponds to the thickness of the bottom cushion and is 6 mm. With such data, the taper angle α is approximately 20°. In case of sudden narrowing, equation (6) is used to calculate the pressure loss, which requires the determination of the coefficients ζ and ε (local resistance and compression). The formula (3) is used to determine the coefficient ε, where $n = F_2/F_1$ – the ratio between the areas of holes in a narrow section and a wide section (23-25):

$$F_1 = 12.56 \text{ mm}^2; F_2 = 3.14 \text{ mm}^2, \quad (23)$$

$$\varepsilon = 0.57 + [0.043/(1.1 - 3.14/12.56)] = 0.62, \quad (24)$$

$$\zeta = \left(\frac{1}{\varepsilon} - 1\right)^2 = \left(\frac{1}{0.62} - 1\right)^2 = 0.376. \quad (25)$$

For the final determination of the value of the local resistance coefficient ζ of the confuser, a correction factor C_c is considered, which depends on the taper angle α of the confuser. At α = 20°, the value $C_c = 0.3$ can be assumed. In this case, according to the formula (4), the following value (26) is obtained:

$$\varepsilon_{\text{conf}} = C_c\zeta = C_c\left(\frac{1}{\varepsilon} - 1\right)^2 = 0.3 * 0.376 = 0.113. \quad (26)$$

Having information about the air flow velocity in a narrow section, it is possible to calculate the pressure loss in accordance with equation (6). Therefore, for the successful application of the method of forming clothes, it is necessary to cut perforations with the shape of a confuser in the lower cushion of the device. The confuser hole, in accordance with aerodynamic principles, ensures a close fit of the material to the working surface of the cushion, as it increases the area on which the vacuum acts during vacuuming. This results in a higher pressure at the top of the cushion due to the larger size of the opening compared to the outlet openings. The size of the perforations was also calculated, considering the maximum breaking load of the deformed fabric. The obtained results indicate the need to create a moderate vacuum, providing a pressure within 1-10^{-3} mmHg, to form clothing elements with the specified dimensions.

The results of experiments conducted on textile materials after hydrothermal treatment under mechanical pressure indicate a loss of these properties of the material at an average level of 15-21%. Based on this, it can be concluded that to improve the processing standards at which the physical-mechanical, and hygienic properties of various textile materials are preserved, improvement of the formation method is required. This method should exclude the negative impact on the clothing parts group from the equipment's working elements, such as matrices and punches. One of the disadvantages of existing devices is their fixed shape of the matrix and punch. It is necessary to change the matrix and punch to create a variety of clothing parts or replace them, which leads to additional costs and reduced productivity.

In the process of manufacturing sewing parts, fabrics or textile materials and bags are subjected to various physical influences: stretching, compression, and moulding. The above factors should be aimed at changing the actual structure of the fabric, thread, and fibres to give a given shape. As a result of these technological influences, the geometric parameters of the threads that make up the fabric and some of the physical and mechanical properties of textile materials naturally change. If the fabric is pressed and the fibres of the thread are plasticised with heated steam, then such a surface differs more than the surface of the fabric that has not been pressed and wet-heat treated.

Experiments conducted in laboratory conditions have shown that the air permeability index for samples before exposure to pressure and moisture is on average, 67.16 cm^3/cm^{2}s (Table 6) [13]. This indicator, after applying pressure and moisture with a mass of 5 kg, decreases to a value of 46.98 cm^3/cm^{2}s; after pressing with a 10 kg press, the device shows 43.74 cm^3/cm^{2}s; after a press load of 15 kg, air permeability decreases to 40.77 cm^3/cm^{2}s; after 20 kg of load, air permeability reduced to 38.01 cm^3/cm^{2}s. It follows that after applying pressure paired with moisture, the air permeability index decreases by 36.95%.

Table 6. Indications of the breathability of the fabric after presses of various weights

Load, m	0	5 kg	10 kg	15 kg	20 kg
Costume fabric	67.16	46.98	43.74	40.77	38.01

Source: compiled by the authors

This can be explained by the fact that in the process of exposure to pressure and moisture, the threads of the fabric flatten, i.e., under the influence of pressure and moisture, acting as a plasticiser, the intermolecular bonds of the fibres of the threads weaken. As a result, the transverse shape and geometric parameters of the threads change, i.e. a circular cross-section of the thread turns into an oval one. This can be compared by the distance between the two threads decreases, and the distance between the central points of the threads increases in their diameter and in the width of the fabric section itself, and thereby the surface coverage of the fabric with threads increases.

Considering that polymer compositions are effective when fixing a given shape of clothing parts, experimental tests were conducted in this part of the study for samples with a polymer coating before and after wet-heat treatment and pressing. In these samples, there was also a decrease in air permeability. Thus, in the samples before pressing, the readings on average are:

1. In a fabric with a 0.5 cm wide strip with a polymer coating from the initial indicator of 16.008 cm^3/cm^{2}s, after a press load of 5 kg, breathability decreases to 15.054 cm^3/cm^{2}s; after 10 kg of press load, breathability decreases to 13.85 cm ^{3}/cm ^{2} s; after 15 kg, breathability has a value of 12.7 cm^3/cm^{2}s; after 20 kg of pressing load, this indicator is 11.7 cm^3/cm^{2}s; it follows that the breathability of fabric with a 0.5 cm wide strip of coating is reduced by 16.9%.
2. In a fabric with a 1 cm wide strip with a polymer coating, the initial air permeability index is 18.368 cm^3/cm^{2}s. Further, after pressing with 5 kg of load, the indicator decreases to 17.138 cm^3/cm^{2}s; after 10 kg of load, the air permeability has a value of 16.182 cm^3/cm^{2}s; after 15 kg of press load, the air permeability decreases to 15.369 cm^3/cm^{2}s; after pressing with 20 kg of load, the indicator is 14.597 cm^3/cm^{2}c. This indicator decreased by 13.9% compared to the initial value.
3. In a fabric with a 2 cm wide strip with a polymer coating, the initial air permeability data reaches 21.39 cm^3/cm^{2}s, after a press load of 5 kg, the air permeability decreased to 21.02 cm^3/cm^{2}s; after 10 kg of the press, the air permeability reaches 20.72 cm^3/cm^{2}s; after 15 kg of the press, the air permeability decreases by 19.68 cm^3/cm^{2}s; after a pressing load of 20 kg, air permeability decreases by 19.2 cm^3/cm^{2}s, which, in total, reduces air permeability from the initial value by 5.8%.

When exposed to high humidity and heat during wet-heat treatment, the bonds between the molecules of the material are weakened and destroyed, and the structure of the material is reshaped in accordance with the deformation of the fibres. After removing moisture (by drying) and lowering the temperature of the material, the bonds between the macromolecules are restored, that is, the deformation of the fibres, threads, and, consequently, the entire material is fixed. However, this fixation of the deformation is temporary; when wearing clothes, the reverse relaxation occurs, and part of the fixed deformation disappears with time. The speed of this reverse relaxation process depends on how similar the conditions of use of the products are to the conditions of wet-heat treatment and wearing of the product, and the closer they coincide, the more firmly the deformation is fixed. The process of restructuring the fibre structure during wet-heat treatment also depends on the chemical composition of the material, its supramolecular structure, and the type of intermolecular bonds [14]. Relaxation processes were traced and investigated in the laboratory to substantiate these processes. From the experimental data obtained, it can be seen that the main relaxation of the examined fabric after wet-heat treatment occurs within 1 hour, totalling in 36.4%.

After two hours, relaxation is 2.7%, after three hours – 0.2%, after four, five and six hours – 0.02%.

To identify the relationship of the WHT process with physical-mechanical properties, for example, with the breaking load, experimental tests were conducted using a device that determines the breaking load index of fabrics and other textiles. The results of the tests and the analysis of the comparative indicators of the breaking load before and after the WHT are shown in the graph (Fig. 11). Experiments conducted in the laboratory have shown that the breaking load of fabrics before wet-heat treatment in the direction of the warp threads is obtained on average 190.074 N, in the direction of the weft threads – 164.996 N, and after wet-heat treatment and pressing, the breaking load index for the warp thread of the material on average decreases to 177.82 N, for the weft thread – 150.256 N. Considering this as a percentage, the index of the breaking load of fabrics after WHT and pressing in the fractional direction of the material decreases by 6.5%, and the breaking load in the transverse direction of the fabric decreases by 8.94%. It follows from this that the breaking load of the examined fabric decreased by an average of 7.72%. This naturally negatively affects the quality indicators of manufactured clothing, in particular, leads to rapid wear of clothing.

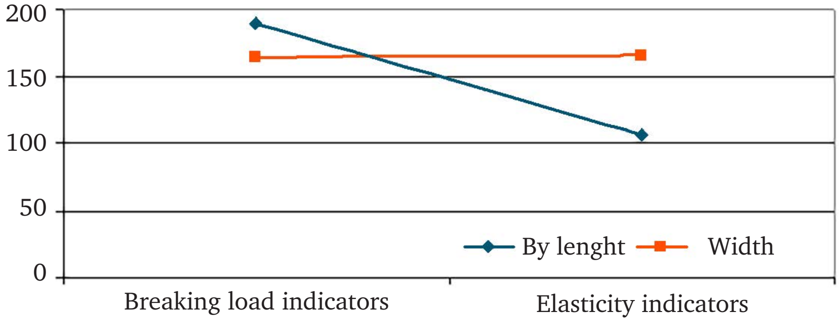


Figure 11. Graph of the impact of the WHT and pressing on the indicators of the breaking load of the material

Source: compiled by the authors

In the next part of the study, experimental tests were conducted on the effects of existing and developed methods of wet-heat treatment on the thickness of the fabric, breaking load, surface density, breathability, stiffness [15]. The results of a comparative assessment of the impact of the conventional and developed WHT method, and the results of the study are presented in Figures 12-16. From the data presented in Figure 12, it can be seen that if the reference thickness value is 1.7 mm, then under the influence of the existing WHT, the fabric thickness index decreases by 32.9% compared to the reference value. When using a vacuum installation in WHT, the thickness of the fabric remains unchanged. This is observed in all examined variants of the textile material.

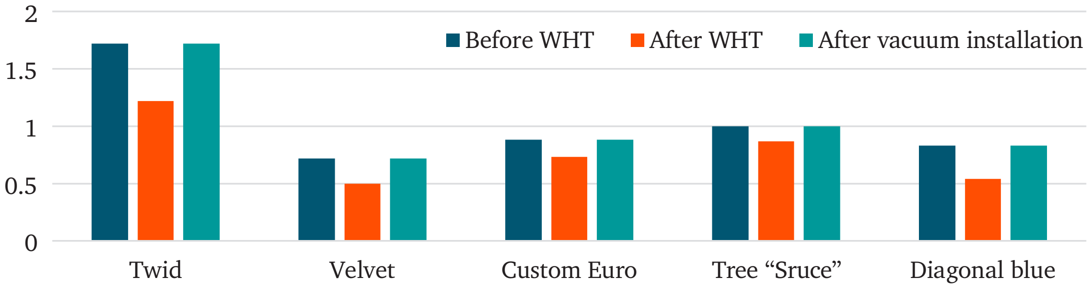


Figure 12. The influence of existing and developed methods of WHT on the indicators of the thickness of the fabric of the examined samples

Source: compiled by the authors

Figure 13 shows the data of experimental tests, with a control value of the breaking load of 845 N, samples under the influence of the existing WHT, this indicator decreases by 21.41% compared with the control value. This is observed in all examined variants of textile material, where the decrease in this indicator is from 17.43 to 33.33% of the control. During the WHT using a vacuum installation, the breaking load indicator remains unchanged.

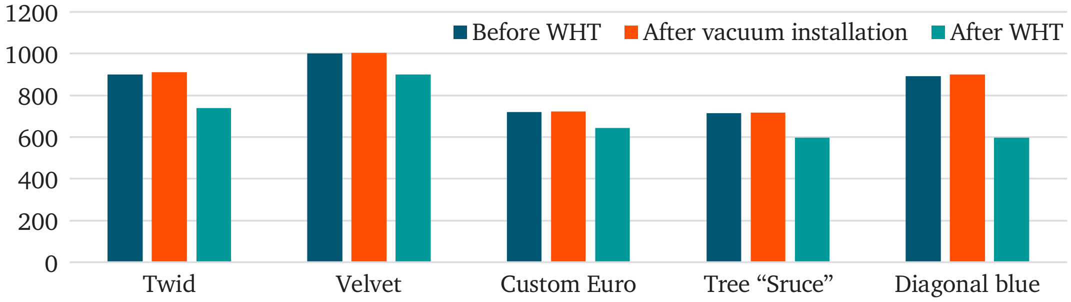


Figure 13. Influence of the existing and developed methods of WHT on the breaking load of the examined samples
Source: compiled by the authors

From the data presented in Figure 14, it can be seen that the surface density index for the control sample and processed according to the existing and proposed technology remains unchanged.

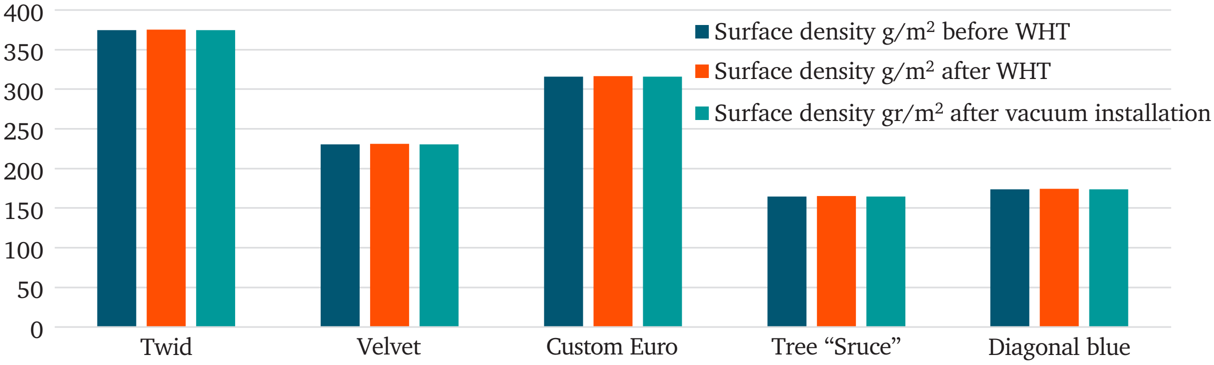


Figure 14. The effect of existing and developed WHT methods on the surface density of fabric
Source: compiled by the authors

From the experimental data presented in Figure 15, it can be seen that if the control value of air permeability is 187.32 cm^3/cm^2s, then in samples under the influence of the existing WHT, this indicator decreases by 12% compared to the control value. This is observed in all considered variants of the textile material, where the decrease in the air permeability index is from 7.17 to 31.53% compared to the control. When using a WHT vacuum installation, the air permeability index remains unchanged [16].

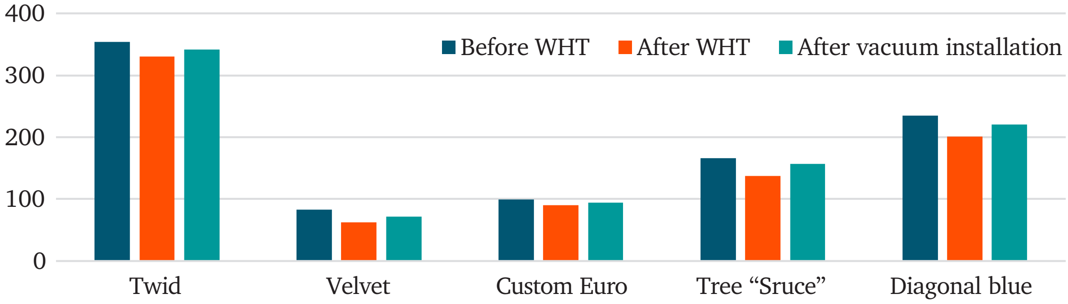


Figure 15. The influence of existing and developed methods of WHT on the breathability of the examined fabrics
Source: compiled by the authors

From the data of experimental tests of the stiffness index of samples presented in Figure 16, it can be seen that if the control stiffness value is 51.36, then this indicator is 22.51% higher for samples under the influence of the existing WHT than for the control sample. This is observed in all examined variants of the textile material, where the increase in the stiffness index is from 14.1 to 28.9% compared to the control.

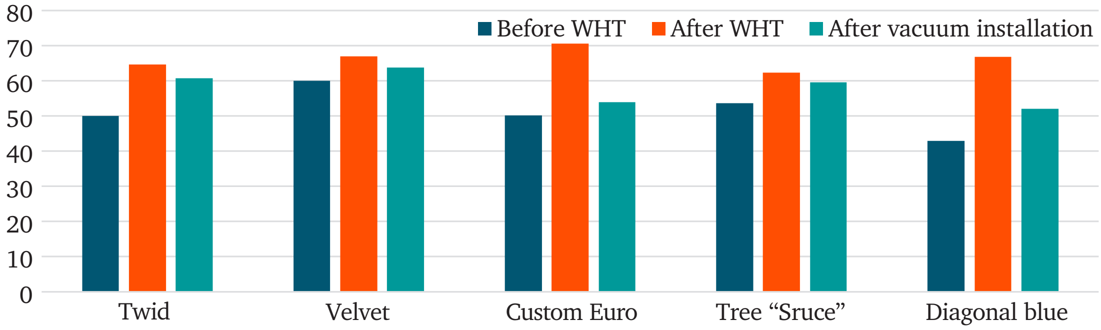


Figure 16. The influence of existing and developed methods of WHT on the stiffness of the fabric of the examined samples
Source: compiled by the authors

Based on the above examination, a comparative graph of the complex of indicators of the textile materials' properties has been developed for an objective assessment of the influence of the existing method of hydrothermal treatment of a vacuum installation and that proposed by the authors (Fig. 17).

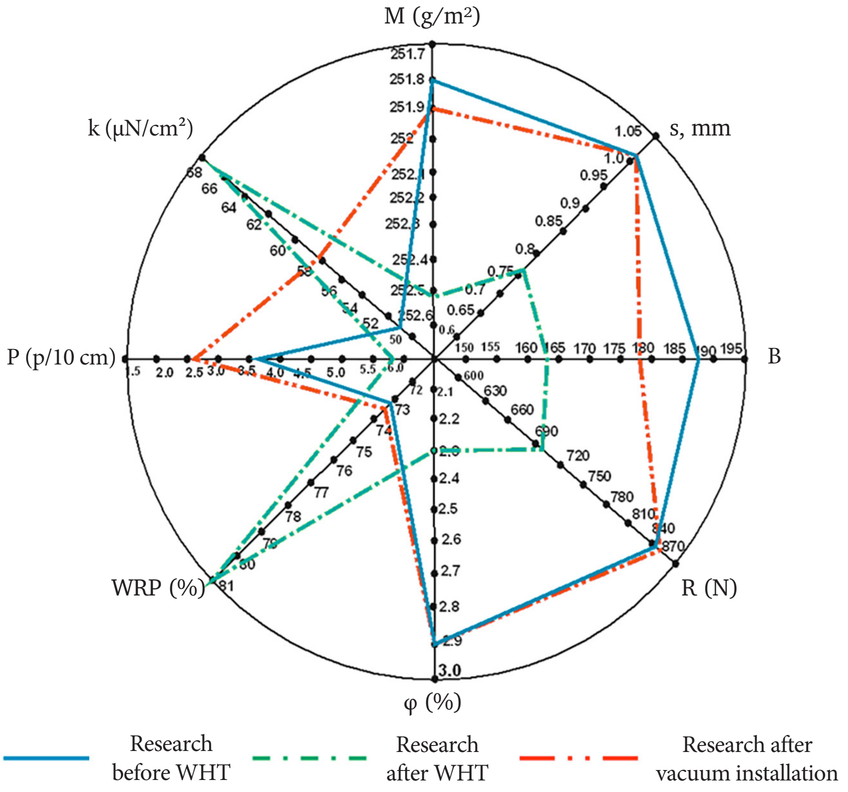


Figure 17. Comprehensive assessment of costume fabrics
Note: k – stiffness (μN/cm^2); P – density (p/10 cm); WRP – water-repellent properties (%); φ – humidity (%); R – breaking load (N); B – breathability; s – thickness (mm); M – mass of material (g/m^2)
Source: compiled by the authors

Thus, summarising the results of the data obtained, according to a comparative assessment of the effects of the existing and proposed methods of WHT of sewing parts, it can be stated that when processing textile material with the existing WHT method, the indicators of fabric thickness, breaking load, and breathability decrease on average by 32.9%, 21.41%, and 22.51%, respectively. Considering the importance of such properties of textile materials as fabric thickness, breaking load, and breathability for ensuring the quality of manufacturing of clothing parts, it can be concluded that the use of a vacuum installation allows maintaining the specified properties of the materials used [17].

Based on the theoretical and experimental examinations conducted, factors were identified, and assumptions were substantiated about the negative impact of the technological process of wet-heat treatment in the aggregate of moulding and pressing on the fabric in the manufacture of sewing parts. It was determined that during the WHT process, the fabric is subjected to pressure, while the threads in the fabric will flatten, flat areas will appear, thereby negatively affecting the physical and mechanical properties of the fabric. Experiments conducted in laboratory conditions have shown that the air permeability index for samples without polymer application and before exposure to pressure and moisture is on average 67.16 cm^3/cm^2s. It follows from this that after applying pressure paired with moisture, that is, after pressing, the air permeability index in sewing products decreases by 36.95%.

The influence of the WHT process on the physical and mechanical parameters of the fabric has been established. Thus, the breaking load and the elasticity index of fabrics before wet-heat treatment are also substantially reduced. It follows that the breaking load of the examined fabric decreased by an average of 7.72%, leading to rapid wear of individual sections of clothing parts. The strength indicators of fabrics to abrasion were examined and it was identified that the strength of the fabric to abrasion decreases after wet-heat treatment by about 15%, which leads to a decrease in the quality indicators of garments.

Discussion

It is difficult to overestimate the importance of the examinations of the effect of hydrothermal treatment on the properties of textile materials since they allow a better understanding of what changes occur in materials during processing and how these changes can affect the quality and durability of the finished textile products. One of the key aspects of such examinations is to determine the optimal parameters of hydrothermal treatment, which will preserve or even improve the physical and mechanical properties of the material. This is important for manufacturers of clothing and textiles, as it allows reducing the percentage of defects and improving the quality of products.

Studies on the effects of hydrothermal treatment of textile materials have long-term implications for both industry and consumers of textile products. Understanding the impact of hydrothermal treatment allows developing more innovative processing methods that consider important aspects of preserving the quality of the material. It also allows enterprises to save resources as optimised processing methods help to reduce energy consumption and raw material costs. An important factor is that the examinations of the hydrothermal treatment process can have an impact on the development of new materials and innovative textiles. Understanding how changes in the structure and properties of materials affect their functionality allows creating products that better meet the needs of modern society.

In the study by Z. Haitang & C. Shan [18] it was observed that after applying pressure paired with moisture, the air permeability index in sewing products can substantially decrease, reaching 30%. This fact indicates that hydrothermal treatment can have a negative impact on the breathability of textile materials and requires more detailed research and finding ways to improve the processing process to minimise the loss of breathability. Evaluating the results obtained by the researchers and this study, the use of a vacuum installation can help maintain the specified properties of the materials used, including fabric thickness, breaking load, and breathability. This is especially important in the clothing manufacturing process, where the quality and characteristics of materials play a key role. However, it is important to conduct additional research and testing to confirm the effectiveness of the vacuum installation and determine the optimal parameters of its application. Such research can contribute to the development of improved technologies and processes for processing textile materials, which, in turn, will increase the quality and durability of the finished textile products.

In the study by Y. Yang *et al.* [19] it was established that after the wet-heat treatment process, the breaking load of the textile fabric is substantially reduced. This observation indicates a potential decrease in the strength of the material after hydrothermal treatment, which can increase the risk of damage, shorten the service life of textiles, and reduce their quality and durability. Such results emphasise the importance of careful control and optimisation of the WHT process to minimise losses in strength and preserve the durability of materials and, consequently, the quality of finished products. In addition, these factors indicate the need to search for new processing methods or the use of improved technologies that could preserve the physical and mechanical properties of textile materials to a greater extent. Effective management of the WHT process can contribute to prolonging the service life of textile products, improving their characteristics, and, as a result, meeting the needs of consumers.

R. Mathangadeera *et al.* [20] in their study noted that after wet-heat treatment, the strength of the fabric is substantially reduced, thereby worsening the overall quality of textiles. These findings highlight the importance of careful control and management of the hydrothermal treatment process to ensure the quality of the final products. Notably, using a vacuum installation provides a potential solution to minimise the negative effects of hydrothermal treatment. The process of vacuuming allows for better retention of the properties of textile materials, which in the end, can contribute to the preservation of the quality and durability of textile products.

In the study by R. Vinayagamoorthy [21], special attention was paid to the damage of textile fibres during hydrothermal treatment. Studies have shown that humidity and elevated temperature, accompanied by this process, can weaken intermolecular bonds in fibres, which leads to their destruction and deformation. This observation indicates the need for careful monitoring and optimisation of hydrothermal treatment conditions to prevent damage to fibres and ensure the safety of textile materials. This once again confirms the importance of research aimed at developing more effective methods of hydrothermal treatment and improving technologies that would preserve the physical and mechanical properties of textile materials during processing.

A. Kumar *et al.* [22] noted that after hydrothermal treatment, fabric thickness indicators can substantially decrease. This fact indicates potential changes in the structure of the material, such as compaction and compression of fibres, which can lead to a decrease in the thickness of the fabric. Reducing the thickness of the material can affect its thermal insulation, protective properties, the appearance, and comfort. Notably, these changes in thickness may be undesirable in some applications where maintaining the original thickness of the material is important. Thus, the results obtained in this study and those of other researchers emphasise the importance of careful control and optimisation of hydrothermal treatment processes, considering the thickness and other properties of the material. This can help preserve the quality and productivity of textiles and contribute to the more efficient use of these materials in various fields, including the textile industry, medicine, and sports applications.

K. Pandey *et al.* [23] noted that the use of new methods of processing textile materials may require additional attention to the technological aspects and control of the hydrothermal treatment process. This means the need to train personnel and create more complex systems to ensure the stability and reliability of the production process. This study, in addition to the paper of the above-mentioned researchers, confirms the need for the development and introduction of new methods and technologies in the hydrothermal processing of textile materials to improve their physical and mechanical properties and the overall quality of the final products. Both studies emphasise the need to improve processing processes to meet the needs of the textile industry for high-quality and durable materials.

Analysing the above-mentioned studies, the potential of research in the field of textile materials processing is great and represents an important step in improving production processes [24]. The relationship between materials' physical and mechanical properties and processing conditions implies that further research may lead to the development of more efficient and sustainable processing methods. Understanding the processes occurring in textile materials as a result of hydrothermal treatment allows optimising this process considering specific requirements and goals, such as maintaining the strength, thickness, and breathability of materials. Achieving this optimisation is of great importance for various industries where the quality and characteristics of textiles are important for comfort and safety [25]. Deeper research in this area can contribute to the development of new processing methods and innovative technologies that will combine high productivity and minimal impact on the properties of materials. Such findings can improve the quality of textile products, reduce production losses, and create more sustainable and efficient textile materials. Ultimately, studies of the effect of hydrothermal treatment of textile materials on their physical and mechanical properties not only contribute to the expansion of scientific knowledge in this field but also have direct application, providing improvement in the quality and functionality of textile products in everyday life and industry.

Conclusions

As a result of the conducted examination, which includes a number of experiments, it was established that the process of hydrothermal treatment can have a substantial impact on the properties of textile materials. A comparative analysis of the existing and proposed WHT methods allowed identifying substantial changes in the indicators of fabric thickness, breaking load, and breathability. On average, it was noted that the use of the existing WHT method leads to a decrease in these indicators by 32.9%, 21.41%, and 22.51%, respectively. This indicates a potential loss of quality of textile materials when using the conventional method. Additionally, the study identified the negative impact of the technological process of wet-heat treatment on the fabric structure.

It was noticed that the fabric is subjected to pressure as a result of pressing. This leads to the flattening of the threads and the formation of flat areas, negatively affecting the material's physical and mechanical properties and reducing its strength. As a result of a series of experiments, it was established that the impact of WHT is accompanied by a substantial decrease in the air permeability of the fabric and can negatively affect the comfort and functionality of textiles. The breaking load and elasticity index also decrease after processing, which increases the risk of wear and reduces the quality of garments. Potential problems associated with conventional WHT methods were identified and the importance of further research in the field of improving processing processes was highlighted.

The introduction of innovative methods, such as the use of a vacuum installation, can help maintain the desired properties of materials and improve the quality of finished products. Areas for further research in this area may also include the development of special recommendations for optimal parameters of hydrothermal treatment and the analysis of the effects of treatment on various types of textile materials and their durability in real operating conditions. The practical importance of this study lies in the fact that the introduction of innovative methods will allow creating better textile products while preserving their characteristics and, ultimately, will contribute to meeting the needs of customers.

Acknowledgements

None.

Conflict of Interest

None.

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Дослідження впливу гідротермічної обробки текстильних матеріалів на їх фізико-механічні властивості та розробка інноваційної технології

Саліх Шукурович Ташпулатов
Доктор технічних наук, професор
Ташкентський інститут текстильної та легкої промисловості
100059, вул. Шохжахон, 5, м. Ташкент, Узбекистан
Джизакський політехнічний інститут
130100, вул. І. Карімова, 4, м. Джизак, Узбекистан
https://orcid.org/0000-0001-5483-2644

Ділрабо Аманбаївна Бахріддінова
Кандидат технічних наук, доцент
Ташкентський інститут текстильної та легкої промисловості
100059, вул. Шохжахон, 5, м. Ташкент, Узбекистан
https://orcid.org/0000-0003-2083-4902

Шахло Нуруллаївна Нутфулаєва
Аспірант
Бухарський інженерно-технологічний інститут
200100, вул. К. Муртазаєва, 15, м. Бухара, Узбекистан
https://orcid.org/0009-0001-8739-4705

Лобар Нуруллаївна Нутфулаєва
Кандидат технічних наук, доцент
Бухарський інженерно-технологічний інститут
200100, вул. Каюма Муртазаєва, 15, м. Бухара, Узбекистан
https://orcid.org/0000-0001-6982-3185

Мухліса Собірівна Мумінова
Магістр, асистент
Бухарський інженерно-технологічний інститут
200100, вул. Каюма Муртазаєва, 15, м. Бухара, Узбекистан
https://orcid.org/0009-0003-8299-9662

Анотація

Актуальність. Дослідження у сфері текстильних матеріалів, а також впливу обробки на їх властивості мають актуальність, оскільки допомагають розробляти ефективніші методи обробки та підвищувати стійкість текстильних матеріалів до впливу різних факторів, що важливо як для виробників, так і для споживачів.

Мета. Метою дослідження було вивчити вплив гідротермічної обробки текстильних матеріалів на їх фізичні та механічні властивості, а також розробити технологію виробництва одягу з використанням нового способу (пристрою) пресового обладнання гідротермічної обробки з композитного матеріалу.

Методологія. При проведенні дослідження використовувався метод аналізу, а також був проведений експеримент, в якому при обробці відібраних зразків тканини використовувалася температура пари, яка не опускалася нижче 160°C, температура на робочих органах преса для формування спинки становила не менше 110°C.

Результати. В результаті було детально вивчено та встановлено вплив гідротермічної обробки на властивості текстильних матеріалів. Проаналізувавши існуючий метод гідротермічної обробки з використанням вакуумної установки, виявлено, що традиційний спосіб обробки призводить до істотного зниження товщини тканини, розривного навантаження та повітропроникності. Також було зазначено, що під час гідротермічної обробки матеріалу відбувається його експонування під впливом тиску. Це призводить до ущільнення та сплющування ниток усередині матеріалу, створюючи плоскі ділянки, що спричиняє несприятливі зміни у фізико-механічних характеристиках тканини.

Висновки. Ці фактори свідчать про потенційне погіршення якості та довговічності текстильних виробів, що може підвищити відсоток браку та негативно позначитися на задоволеності споживачів. Дане дослідження також вказує на перспективи використання вакуумної установки в гідротермічній обробці, що дозволяє зберегти бажані властивості матеріалів, покращуючи якість кінцевих продуктів. Практичне значення результатів цього дослідження полягає у можливості покращення якості текстильних виробів та зниження ступеня пошкодження матеріалів, що важливо для забезпечення більш тривалої експлуатації текстильної продукції та підвищення задоволеності споживачів

Ключові слова: формоутворення виробів; структура тканини; деформація волокон; вакуумне встановлення; розривне навантаження; повітропроникність