APPLICATION OF STATISTICAL METHODS IN OPTIMIZING THE THICKNESS OF PROTECTIVE CLOTHING MATERIALS IN EXTREME CONDITIONS

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Abstract: This study is devoted to improving the design process of highly heat-retaining and ergonomic special clothing for military personnel serving in extremely cold conditions. The microscopic structure and high thermal insulation properties of rabbit wool were scientifically analyzed in the study. Nonwoven materials made from 50/50 mixtures of rabbit wool, camel and sheep wool with polyester fibers were studied as part of the heat-retaining package. The results of the analysis showed that polyester fibers enrich the thermal properties of natural wool with strength and moisture management (wicking) indicators. Within the framework of constructive solutions, it was achieved to reduce the weight of the clothing and maintain maximum freedom of movement by optimizing the "Freedom Additive" (EQ), "Package Additive" (PQ) and general constructive additives (KQ). The results of the study show that the developed special military clothing is distinguished by its lightness, effective moisture management and high heat retention indicators compared to traditional models. This scientific solution is of significant practical importance in ensuring the operational mobility and safety of military personnel in extreme conditions.

Keywords: rabbit down, extreme conditions, thermal insulation materials, polyester fibers, structural allowances, ergonomics, military clothing, non-woven materials

ПРИМЕНЕНИЕ СТАТИСТИЧЕСКИХ МЕТОДОВ ДЛЯ ОПТИМИЗАЦИИ ТОЛЩИНЫ МАТЕРИАЛОВ ЗАЩИТНОЙ ОДЕЖДЫ В ЭКСТРЕМАЛЬНЫХ УСЛОВИЯХ

Аннотация: Данное исследование посвящено совершенствованию процесса проектирования специальной одежды с высокими теплозащитными и эргономическими свойствами для военнослужащих, выполняющих задачи в условиях экстремально низких температур. В работе проанализированы уникальные природные свойства кроличьего пуха, его микроскопическая структура и способность удерживать воздух, обеспечивающие высокую теплоизоляцию. В ходе исследования были изучены нетканые материалы на основе смесей кроличьего пуха, верблюжьей и овечьей шерсти с полиэфирными волокнами в соотношении 50/50. Анализ показал, что полиэфирные волокна не только сохраняют теплозащитные свойства натуральной шерсти, но и улучшают показатели прочности и влагоотведения (wicking). В части конструктивных решений обоснована важность оптимизации «прибавки на свободу» (ПС), «пакетной прибавки» (ПП) и общей конструктивной прибавки (ОКП), что позволило снизить массу изделия при сохранении максимальной свободы движений. Результаты исследования подтверждают, что разработанная модель специальной военной одежды превосходит традиционные аналоги по легкости, эффективности управления влагой и теплозащитным характеристикам. Данное научно обоснованное решение имеет важное практическое значение для обеспечения оперативной подвижности и безопасности военнослужащих в экстремальных холодных условиях.

Ключевые слова: кроличий пух, экстремальные условия, теплоизоляционные материалы, полиэфирные волокна, конструктивные прибавки, эргономика, военная одежда, нетканые материалы.

EKSTREMAL SHAROITIARDA HIMOYA KIYIMLARI MATERIALLARI QALINLIGINI OPTIMALLASHTIRISHDA STATISTIK USULLARNI QO‘LLASH

Annotatsiya: Mazkur tadqiqot ekstremal sovuq sharoitlarda xizmat qiluvchi harbiy xizmatchilar uchun yuqori issiqlik saqlovchi va ergonomik maxsus kiyim loyihalash jarayonini takomillashtirishga bag‘ishlangan. Tadqiqotda quyon jun-mo‘yining mikroskopik tuzilishi va yuqori issiqlik izolyatsiyasi xususiyatlari ilmiy jihatdan tahlil qilindi. Issiqlik saqlovchi paket tarkibida quyon jun-mo‘yi, tuya va qo‘y junlarining poliefir tolalari bilan 50/50 nisbatdagi aralashmalari asosida tayyorlangan noto‘qima materiallar tadqiq etildi. Tahlillar natijasida poliefir tolalari tabiiy junning issiqlik xossalarini mustahkamlik va namlikni boshqarish (wicking) ko‘rsatkichlari bilan boyitishi aniqlandi. Konstruktiv yechimlar doirasida “Erkinlik qo‘shimchasi” (EQ), “Paket qo‘shimchasi” (PQ) va umumiy konstruktiv qo‘shimchalarni (KQ) optimallashtirish orqali kiyimning vaznini kamaytirish hamda harakat erkinligini maksimal darajada saqlab qolishga erishildi. Tadqiqot natijalari shuni ko‘rsatadiki, ishlab chiqilgan maxsus harbiy kiyim an’anaviy namunalarga nisbatan yengilligi, namlikni samarali boshqarish qobiliyati va yuqori issiqlik saqlash ko‘rsatkichlari bilan ajralib turadi. Ushbu ilmiy yechim ekstremal sharoitlarda harbiy xizmatchilarning operativ harakatchanligini va xavfsizligini ta’minlashda muhim amaliy ahamiyat kasb etadi.

Kalit so‘zlar: quyon jun-mo‘yi, ekstremal sharoitlar, issiqlik saqlovchi materiallar, poliefir tolalari, konstruktiv qo‘shimchalar, ergonomika, harbiy kiyim, not’qima materiallar.

Throughout human history, clothing has served not only to protect the body from environmental influences, but also as a means of expressing social culture and aesthetic taste. In modern society, special clothing is of particular importance, aimed at ensuring human safety, health and productivity in certain conditions and types of activity. Special heat-retaining clothing is a vital necessity, especially for people working or living in low-temperature conditions, and directly determines their health and quality of life.

Extreme cold environments pose a serious threat to human health, safety and productivity. Therefore, the continuous development of innovative textile technologies is essential for effective operation in these conditions.

The effectiveness and safety of military personnel in extreme cold conditions primarily depends on the ability of their special clothing to retain heat. Traditional protective equipment for military personnel serving in cold climates often limits their activity, freedom of movement, and ability to regulate their body temperature. Therefore, the main goal of this research is to develop special military special clothing designed for extreme cold conditions, with high heat-retaining properties, but at the same time lightweight, comfortable, and not restricting freedom of movement.

Based on the results of scientific research, this project focused on the effective use of the unique natural properties of rabbit wool. Rabbit wool, due to its small and thin fibrous structure, creates a large number of microscopic voids filled with air. This provides a high level of heat retention. The research involved the use of purified and specially processed rabbit wool fibers, as well as their optimal mixtures with synthetic polyester fibers, for example:

- 50% rabbit fur / 50% polyester;
-50% camel wool / 50% polyester;
-50% sheep wool / 50% polyester fiber nonwoven materials were studied.

These blends combine not only the high heat retention capacity of natural wool, but also the strength, wicking, and quick drying properties of polyester.

The results of scientific research on constructive solutions have proven the importance of multi-layer structures, outer layers and ergonomic additions . In particular, by reducing the “Freedom Addition” (EQ), “Package Addition” (PQ) and the general constructive addition (KQ), it was possible to reduce the weight of the clothing and maintain maximum freedom of movement. This is especially important for the operational movement of military personnel and the performance of active tasks.

As a result, the special military clothing made of rabbit fur developed in this study has properties such as high heat retention, low weight, comfort, freedom of movement, and effective moisture management compared to traditional methods, and is a scientifically based and practically significant solution capable of ensuring the efficiency and safety of military personnel in extreme cold conditions.

Procedure for conducting a full-factorial experiment (FTE). Evaluation and analysis of the resulting models.

Multivariate or factorial design of an experiment refers to a design in which the levels of all influencing factors are changed simultaneously.

This design method allows for high-precision results with a small number of experiments. Each regression coefficient in the mathematical model obtained as a result of experiments based on factorial design is found as a result of all N experiments, therefore its variance is N times smaller than the variance of the experimental error.

If the levels under investigation for each factor are the same and denoted by k , the number of non-repeating combinations in the probability or TOT matrix is determined as follows:

$$\mathbf{N = k^{m}}$$

Table 1 , as the number of factors in a full-factor experiment increases, the number of experiments in the matrix also increases sharply. Therefore, it is recommended to use a full-factor experiment in cases where the number of factors affecting the object is 4 or less. If the number of influencing factors in the study is more than 4, it is advisable to sort them by their significance level and use TOT or use completely different matrices.

The full factorial design matrix is TOT 2. Here, "2" indicates that the experiments are conducted at two levels, i.e., minimum and maximum levels. The main reason for this is that TOT is based only on the assumption that there is a linear relationship between the input factors and the output parameter, and therefore, if the experiment is conducted at the two points mentioned above, the other points lie on this line.

Rabbit fur non-woven material package for extreme conditions
o miles change levels

Table 1

Factors' change levels

Factors		Measurement unit	Levels of change			Change interval
Name	Codes		-1	0	+1	
clothing package thickness	X_1	cm	2.8	3	3.2	0.2
addition to the clothing package	X_2	cm	19.6	20.5	21.4	0.9

Table 2

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Full-factor experiment TOT 2 matrix

T/r	Factor levels		Air permeability, (cm ³/cm ².sec)		Average $\overline{Y}_{H.O^{ъ}.}$	$S^2\{\overline{Y}_{H.O^{ъ}.}\}$ dispersion	Heat retention, %		Average $\overline{Y}_{I.S.}$	$S^2\{\overline{Y}_{I.S.}\}$, dispersion
HE IS	1	2	$\overline{Y}_{I.S.1}$	$\overline{Y}_{I.S.2}$			$\overline{Y}_{I.S.1}$	$\overline{Y}_{I.S.2}$		
			3.45	3.37	3,410	0.003	76.1	75.91	76,005	0.018
			3.24	3.34	3,290	0.005	75.65	75.44	75,545	0.022
			3,41	3,17	3,290	0,029	75,48	75,03	75,255	0,101
			2,98	2,75	2,865	0,026	74,57	74,93	74,750	0,065

The experiments were randomized using a random number table before being conducted in duplicate. The results were processed and summarized as shown in Tables 1 and 2. According to the rules for processing experimental results, the experimental repeatability was initially determined. For this, the calculated value of the Cochrane criterion was found and compared with the tabulated value.

1) Consistency is checked using the Cochrane criteria.

Cochrane criteria The tabular value was determined as follows.

$$G_{jad}=\{P_H=0.95;f=m-1=2-1=2;N=4\}=0.7679$$

$\overline{Y}_{H.O^{ъ}.}$ - The similarity is defined as follows:

$$G_{H.O^{ъ}}=\frac{S_u^2\{y\}max}{\sum_{u=1}^{N} S_u^2\{y\}}=\frac{0,029}{0.0635}=0,454$$

$\overline{Y}_{I.S.}$- The similarity is defined as follows:

$$G_{I.S}=\frac{S_u^2\{y\}max}{\sum_{u=1}^{N} S_u^2\{y\}}=\frac{0,101}{0.2062}=0,491$$

$C_y^2\{й\}$max-maximum variance of the test;

$\sum_{y=1}^{H} C_y^2\{й\}$- the sum of all serial dispersions.

$G_H < G_{jad}$ Since the condition is met, similar experiments are repeatable, that is, identical.

Since the Cochrane criterion is met, the regression coefficients can be calculated. The general form of the regression equation is as follows:

$$y=b_0+b_1x_1+b_2x_2+b_1x_1x_2$$

The coefficients in the equation are calculated using the following formulas:

$$b_0=\frac{1}{N}\sum_{u=1}^{N}\bar{y}_u=\frac{\bar{y}_1+\bar{y}_2+...+\bar{y}_N}{N} \qquad (1)$$

Coefficients of linear terms:

$$b_i=\frac{1}{N}\sum_{u=1}^{N}x_{iu}\cdot\bar{y}_u=\frac{x_{i1}\cdot\bar{y}_1+x_{i2}\cdot\bar{y}_2+...+x_{iN}\cdot\bar{y}_N}{N} \qquad (3)$$

Calculation of regression coefficients for air permeability.

$$b_0=\frac{1}{4}(3.410+3.290+3.295+2.865)=3.215$$
$$b_1=\frac{1}{4}(-3.410+3.290-3.295+2.865)=-0.1375$$
$$b_2=\frac{1}{4}(-3.410-3.290+3.295+2.865)=-0.1350$$
$$b_{12}=\frac{1}{4}(3.410-3.290-3.295+2.865)=-0.0775$$

Calculation of regression coefficients for thermal conductivity.

$$b_0=\frac{1}{4}(76.005+75.545+75.255+74.750)=75.388$$
$$b_1=\frac{1}{4}(-76.005+75.545-75.255+74.750)=-0.24125$$
$$b_2=\frac{1}{4}(-76.005-75.545+75.255+74.750)=-0.3863$$
$$b_{12}=\frac{1}{4}(76.005-75.545-75.255+74.750)=-0.0113$$

From the obtained calculation results, the general form of the regression model is written as follows.

Regression equation for air permeability

$$Y_R=3.215-0.1375x_1-0.1350x_2-0.07775x_1x_2$$

Regression equation for thermal conductivity

$$Y_R=75.388-0.24125x_1-0.3863x_2-0.0113x_1x_2$$

The estimation of the coefficient values of the regression equations $t_{jad}=\{P=0,95;N=4;\}$ $t_{jad}=2,776$ is equal to according to the Student's t-test. If $t_{jad}<t_{his}$ so, the coefficient is significant. If all regression coefficients are significant, the model is inadequate.

The significance of the regression coefficients t_R is determined using the Student's t-test calculation criterion:

$$t_R\{b_i\}=\frac{|b_i|}{S\{b_i\}}$$
$$S\{b_i\}=\frac{S^2\{Y\}}{N}$$

HO' - $S\{b_i\}=\sqrt{\frac{0.00764}{4}}=0.0437$ **IS** -$S\{b_i\}=\sqrt{\frac{0.02577}{4}}=0.08026$

where is $S^2\{Y\}$the linear variance. It is determined using the following formula:

$$S^2\{Y\}-\frac{1}{m}S^2\{\overline{Y}\}$$

HO' -$S^2\{Y\}=\frac{0.01528}{2}=0.00764$ **IS** -$S^2\{Y\}=\frac{0.05154}{2}=0.02577$

where m is the number of test repetitions.

$S^2\{\overline{Y}\}$- recovery variance. It is determined using the following formula:

$$S^2\{\overline{Y}\}=\frac{S^2\{Y\}}{N}$$

HO' -$S^2\{\overline{Y}\}=\frac{0.0611}{4}=0.01528$ **IS** -$S^2\{\overline{Y}\}=\frac{0.2062}{4}=0.05154$

where N is the number of trials.

Calculation of Student's criterion for air permeability

$t_R\{b_0\}=\frac{|3.215|}{0.0437}=73.5758$;$t_R\{b_1\}=\frac{|0.1375|}{0.0437}=3.1467$

$t_R\{b_2\}=\frac{|0.1350|}{0.0437}=3.0894$; $t_R\{b_{12}\}=\frac{|0.0775|}{0.0437}=1.7736$;

2. Calculation of Student's criterion for thermal conductivity

$t_R\{b_0\}=939.268$; $t_R\{b_1\}=3.0057$; $t_R\{b_2\}=4.8122$; $t_R\{b_{12}\}=0.1401$;

Therefore, $t_R\{b_{12}\}-$the coefficient was considered insignificant and was discarded because it was smaller than the Student's criterion. After discarding the insignificant coefficients, the regression equations took the following form:

Regression equation for air permeability .

$$Y_R=3.215-0.1375x_1-0.1350x_2$$

Regression equation for thermal conductivity

$$Y_R=75.388-0.24125x_1-0.3863x_2$$

To assess the adequacy (fit) of the above equations

, the F– Fisher criterion was used, namely:

$$F_{his}=\frac{S^2_{ad}}{S^2\{Y\}}$$

where is $S^2_{ad}$the adequacy variance.

The variance of adequacy is a measure of the deviation of the estimated values from the actual values. If $F_{his} < F_{jad}$, the model is considered adequate.

1. Checking the adequacy of the variance of the regression equation for air permeability

$$F_{jad}=(P=0,95;\ f_{ad}=N-M=4-2=2;\ f_{tak}=N(m-1)=4(2-1)=4.$$

$$F_{jad}=19,25 \text{ ga teng}$$

$$S^2_{ag}=\sum_{i=1}^{N}(y_{taj}-y_{his})^2/N-M=0.1394/(4-2)=0.06972$$

$$F_{his}=\frac{S^2_{ag}}{S^2_{yi}}=\frac{0.06972}{0.00764}=9.1289$$

$$F_{his}<F_{jad}=9.1289<19.25$$

2. Heat retention The adequacy variance of the regression equation is :

$$F_{jad}=(P=0,95;\ f_{ad}=N-M=4-2=2;\ f_{tak}=N(m-1)=4(2-1)=4.$$

$$F_{jad}=19,25 \text{ ga teng}$$

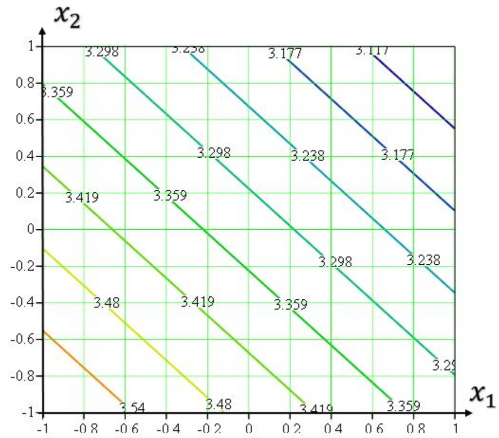
$$S_{ag}^2=\sum_{i=1}^{N}\left(y_{taj}-y_{his}\right)^2/N-\lambda=0.2903/(4-2)=0.1451$$

$$F_{his}=\frac{S_{ag}^2}{S_{yi}^2}=\frac{0.1451}{0.02577}=5.633$$

$$F_{his}<F_{jad}=5.633<19.25$$

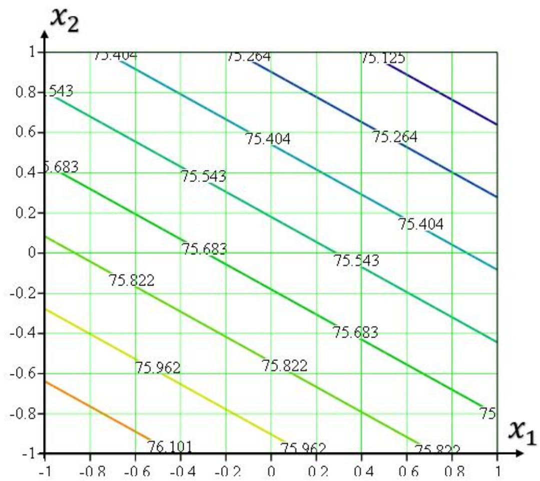
So, Regression equations $\mathbf{F_{his}<F_{jad}}$ are considered adequate if this condition is met.

In order to analyze and understand the above regression equations, their isolines were constructed using the "Mathcad" program and are presented below.



1. Isoline of the regression equation obtained for air permeability

x_1−the air permeability of the fabric $x_1-(-1\div-0.6)$ and the gap are improved by changing $x_2-(-1\div-0.6)$ the thickness of the non-woven material and x_1−the additional gap in the garment package −1÷1. In natural values x_1−2.80÷2.86, x_2−it corresponds to 19.60 .÷19.96



2. Heat storage isoline of the regression equation obtained by

x_1− insulation of the fabric $x_2-(-1\div-0.6)$ is improved x_1−2.80÷2.92 by varying $x_1-(-1\div-0.4)$ the thickness of the non-woven material and x_2−the additional -1 to the garment package . In natural values ÷1, x_2−19.6 ÷corresponds to 19.96 .

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