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ANALYTICAL APPROACH TO THE INSULATION PROPERTIES OF SPECIAL CLOTHING

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The emergence of a variety of textile materials with new properties, the development of computer technology has changed the traditional approach to the processes of selecting materials, design and producing special clothing. The article discusses the analytical approach of Russian and foreign scientists in the investigation of insulating properties of special clothing. Regression modeling techniques, optimization theory with the use of computer technology are widely used under these conditions. The study examines the different regression models, the results of the correlation, factor analysis in the calculation of the correlation of various parameters: the total thermal resistance, surface density, water vapor permeability, air permeability, hygroscopicity, surface filling, total porosity, thickness, water yielding. On the basis of calculations of required insulation protective clothing, the time of continuous stay in the cold for southern region of Russia workers engaged in Oil production we have developed a computer program.

Based on the proposed regression model the problem of maximizing the quality criterion has been solved. With the help of quadratic programming methods we defined: the optimum value of the thickness of the package material, the thickness of the coating materials, the minimum possible value of air permeability in the end – a target set insulation materials. Due to this approach it has been possible to establish the maximum acceptable construction of special

clothing for such conditions, as well as to adapt the process of picking a package of materials for these clothes. The issue complete materials package and the need to study the properties of thermal insulation materials selected as close as possible for creating a comfortable working environment are related in this article.
Designing heatproof special clothing includes the processes of its testing under different conditions. One of the problems to be solved in the course of our tests is an analysis of changes in the thermal fields of workers with different body masses in the process of employment.
K e y w o r d s : *The insulating properties of special clothing; materials package; a set of clothes; special clothes design; regression modeling; optimization theory; the thermal radiation field of a worker; insulation special clothing.*

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Иващенко И.Н., Севрюгина Н.И., Шмалько С.П.
АНАЛИТИЧЕСКИЕ ПОДХОДЫ К ИЗОЛЯЦИОННЫМ СВОЙСТВАМ СПЕЦИАЛЬНОЙ ОДЕЖДЫ

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Появление разнообразных текстильных материалов с новыми свойствами, развитие компьютерных технологий изменили традиционный подход к процессам выбора материалов, проектирования и производства специальной одежды. В статье рассматривается аналитический подход российских и зарубежных ученых в вопросах исследования изоляционных свойств специальной одежды. В этих условиях широко применяются методы регрессионного моделирования, теории оптимизации с применением компьютерных технологий. В исследовании рассматриваются различные регрессионные модели, результаты корреляционного, факторного анализов в расчетах взаимосвязей различных показателей: суммарное тепловое сопротивление, поверхностная плотность, паропроницаемость, воздухопроницаемость, гигроскопичность, поверхностное заполнение, общая пористость, толщина, влагоотдача. На основе полученных расчетов необходимой теплоизоляции защитной одежды, времени допустимого непрерывного пребывания на холоде работников нефтедобывающего производства южного климатического региона России разработана программа для ЭВМ.
На основе предложенной регрессионной модели решена задача максимизации критерия качества. Методами квадратического программирования определены: оптимальное значение толщины пакета материалов, толщины покровных материалов, минимально возможное значение воздухопроницаемости, в итоге – прогнозируемая теплоизоляция комплекта материалов. Благодаря такому подходу оказалось возможным установить максимально приемлемую для заданных условий конструкцию комплекта специальной одежды, а так же адаптировать процесс комплектации пакета материалов для данной одежды. В представленной статье соотносится вопрос комплектации пакета материалов и необходимости исследования теплоизоляционных свойств выбранных материалов, максимально приближенных к созданию комфортных условий труда.
Проектирование теплозащитной специальной одежды включает в себя процессы ее испытаний в различных условиях. Одна из задач, решаемых в процессе наших испытаний – это анализ изменений тепловых полей работников с различными массами тела в процессе трудовой деятельности.
К л ю ч е в ы е с л о в а : *изоляционные свойства специальной одежды; пакет материалов; комплект одежды; проектирование специальной одежды; регрессионное моделирование; теория оптимизации; тепловые поля работника; теплоизоляция специальной одежды.*

Introduction

Maintaining thermal homeostasis of a person may be possible if you use multilayer special clothing, as human activity is constantly in contact with the environment. Russian and foreign scientists often turn to the subject of the insulating capacity of clothing. Despite this universal recommendations of the analytical approach to the rational structure of materials package in the complete insulation of special clothing at a given time do not exist.

Material and methods

The development of computer technology and the emergence of textile materials with new properties have significantly changed traditional approaches to the processes of designing and producing special clothing. Under these conditions, the methods of regression modeling and optimization theory are widely used [1–6, 9].

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Results and discussion

Regression analysis of dependency is widespread, it provides an information basis for selecting structural funds to ensure dynamic matching clothing, a study [1] used the mathematical model of multiple regression and quadratic nonlinear regression changes measurable traits in the dynamics, depending on the amplitude of the angle changes in the segments of the upper and lower extremities. Since the distance from the waist line to infrabuttock crease (folds in flexion (extension) leg at the knee joint, while torso is (1):

$$Y_{16} = 52 + 1.828X_1 + 1.305X_2. \tag{1}$$

At the bend of the trunk with horizontal abduction (powered) hand in the shoulder joint of the back length to the waist (2) and the width of the back (3) have the form:

$$Y_1 = 2.324 + 0.016X_7 + 0.047X_8; \tag{2}$$

$$Y_6 = 15.18 + 0.000007X_7^2 - 0.004X_8^2 - 0.00003X_1X_2 + 0.749X_8. \tag{3}$$

The studies have been carried out and performed predicting the thermal resistance of knitted fabrics [2] using correlation analysis,

conducted sensitivity analysis and calculated optimization (minimum and maximum values) of the parameters the properties of such webs, of which these are the surface density and heat capacity by the National Pakistan Textile University (4, 5, 6).

$$R_{ct} = -234.11 + 3.117\Gamma + 117.97C + 7.73/ - 17.57\ C^2 - 0.37 TtxC^{0.04\Gamma z^2}; \qquad (4)$$

$$R_{ct} = -271.42 + 110.64C + 211.33t - 0.05m - 13.85C^2 + 0.0002m^2 - 37.65Cxt + 0.05Cxm - 0.24txm; \ (5)$$

$$R_{ct} = -157.44 + 2.61Tt + 40.82C - 38.311 + 274.921 - 0.23m - 0.05Tt^2 + 16.23Cx - 98.88Cxt + 0.08. (6)$$

The Hong Kong Polytechnic University studied clothing insulation taking into account the wind using anthropoid thermal mannequin simulating the heat and mass transfer between the human body and the environment [3], developed and subjected to extensive analysis of the regression model (7,8), revealed that clothing insulation decreases with an increase in the wind speed and the speed of human walk. However, the climate chamber with human participation gives more realistic results, but it requires sophisticated equipment.

$$\frac{I_t}{I_{st}} = \frac{1}{1 + 0.27\ (V_{wind} + 1.8 V_{walk} - \nu_0)} \qquad (7)$$

$$\frac{R_t}{R_{st}} = \frac{1}{1 + 0.32\ (V_{wind} + 1.8 V_{walk} - \nu_0)} \qquad (8)$$

The Indian Institute of Technology studied the properties of multi-layered clothing and packages used materials [4]. A mathematical model for predicting the comfort of the human condition (9) was established and experimentally confirmed. It is conducting a study of heat transfer through different materials packages to suit the air gap between them, but the climatic conditions were taken into account.

$$\rho c_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(k_c \frac{\partial T}{\partial x}\right) - \frac{\partial q_r}{\partial x} \qquad (9)$$

The Rumanian National Institute of Research and Development Studies textile laminates packages containing aramid and viscose fibers to protect against high temperatures [5]. As a result, it created and experimentally verified mathematical model to assess the comfort of special clothing using indicators of air permeability and water vapor permeability, but excluding the impact of climatic conditions (10).

$$R_{et} = 243.88x^2 + 944.61x + 7595.7. \qquad (10)$$

Figure 1 – Technology of forming adjustable structure of heat-shielding clothes with thermo-physical parameters.

Previously, we have carried out the studies to establish the effect of harmful production and climatic factors on the human body [6], as well as a package of advanced materials to protect against the cold [7], coating and thermal insulation materials with different combinations of fibers in structures taking into account climatic conditions and the energy expenditure operating. On the basis of calculations required insulation protective clothing, the time allowable continuous stay in the cold for workers of Oil production from southern region of Russia the computer program was developed (Figure 1).

Then, factor analysis of the relationship between indicators of thermal parameters of coating materials heat-shielding clothes was carried out [8, 9], among them are the total thermal resistance, surface density, water vapor permeability, air permeability, hygroscopic property, surface filling, total porosity, thickness, water yielding.

We obtained regression models listed relationships: the quadratic regression relationship (Figure 2) of the total thermal resistance of the air permeability of the coating materials (X) and the thickness (Y) and an equation was got (11):

$$U = 0.2625 + 1.1451X - 0.0001Y - 0.741X^2\ 20.005\ 4XY - 3.011 \cdot 10^{-5}Y^2. \ (11)$$

The correlation index is relatively high, it is equal to 0.98. Insignificant factors are: the linear term for breathability (α = 0.94), the quadratic term for the air permeability (α = 0.57). The significance of all the members of the regression for the thickness, great importance is the high level of importance to the members of the pair to the thickness and air permeability (α = 0.33). Therefore, from the model (11) the linear and quadratic terms with breathability were driven and the following regression model was obtained (12):

$$U = 0.2048 + 1.3470X - 0.8293X^2 - 0.0090YX. \qquad (12)$$

All parameters of the model are significant. The maximum level of significance of 0.0017. Correlation index fell slightly to 0.979, the relative accuracy of the forecast is 4% (Figure 2,3).

The problem of optimal choice of materials for the package comfortable working conditions in the tested clothes was posed and solved [10]. Insulation special clothing was selected as a quality criteria. Equations connection optimization problems were obtained by regression analysis of the correlation between the structural and thermal parameters set heatproof materials multilayered garments, such as insulation, surface density, air permeability, thickness of the coating material that is acceptable for a given packet of materials and ambient temperature. Quadratic regression equation (13) for heat insulation kit (U) of the package thickness (X), the thickness of the coating materials (Y) and the air permeability (Z) was recieved:

$$U = 0.77Y + 0.035X - 0.3Y2 - 0.00045X2 - 0.0064ZY - 0.0128YX. \qquad (13)$$

Correlation index obtained according to R = 0,998; analysis shows the relative residual prediction error is less than 1.5%. Figure 4 is represented as graphically illustration of obtained quadratic correlation (13).

Based on the proposed regression model we solved the problem of maximizing the quality criterion. With the help of quadratic methods programming we defined: the optimal value of the package material thickness equal to 29.5 mm; the optimum value of the thickness of the coating materials – 0.664 mm; the minimum possible value of air permeability – 0 dm³/m²s; and the predicted insulation toolkit – 0.777 cm²/W.

Due to the results it appeared the possibility of more accurately performing calculations of the thickness of coating materials which allow determining in the design of clothing materials package with maximum insulation, meeting all modern requirements. So accounting principles for the formation of thermal insulation, heat preservation of homeostasis due to the properties of
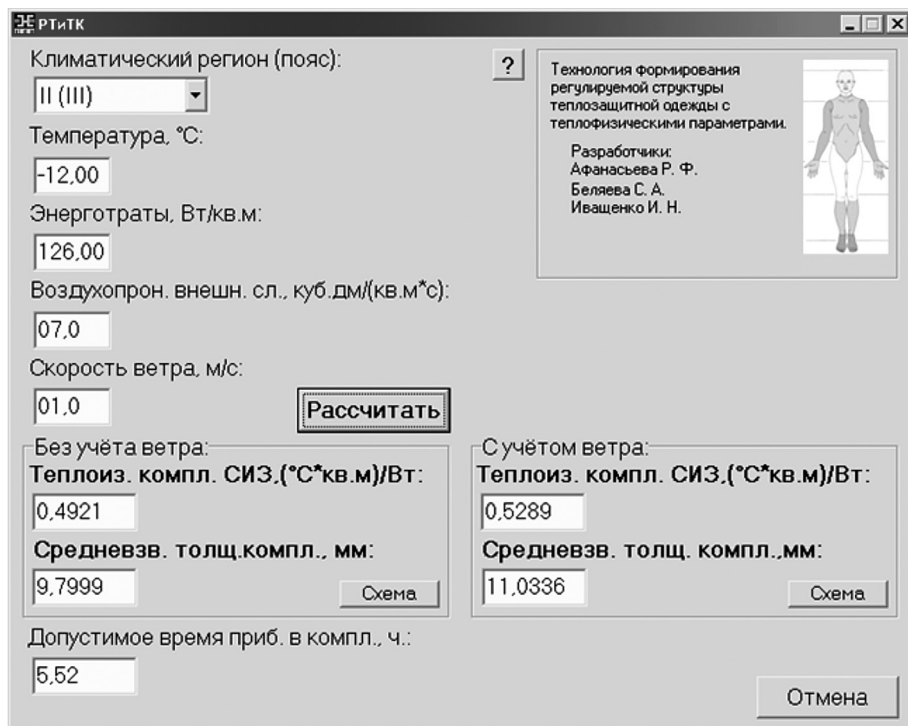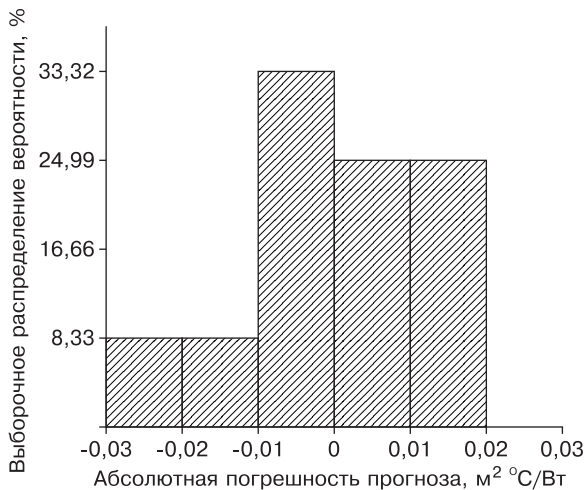
Figure 3 – Histogram of fragments of regression model. On the abscissa axis: the absolute error of the forecast, м² °C/W; on the ordinate axis: selective probability distribution, %.

air permeability, water vapor permeability, and others that providing «breathing» properties of clothes it can achieve proportionality compliance of basic hygiene principles, reduce the impact of negative factors of the environment, preserving health.

Designing heat protective clothes for work includes its testing under different conditions. One of the problems to be solved in the course of our tests is the definition of change of thermal field workers with different body masses in the course of employment.

The uniform «oilman» has been created at the department of architecture and design of the Kuban State University. It is designed for people working outdoors in harsh environments with rapid temperature changes. At this stage of the research we studied the thermal radiation of the human field (thermal load), provided the suit «oilman» for people with different body masses in conditions close to comfortable. The studies were carried out at the Department of Physics and Information Systems of the Kuban State University with a thermal imager «testo 885-2», the data were processed and analyzed thermal images using specialized software Testo IRSoft.

Thermal image of a man (Figures 5 and 6) is divided into segments containing the open areas of the body and limbs closed. The thermograms obtained after intense movements differ from thermal images alone. Thermal radiation of the human field is higher than the intensity of his physical activity.

Fixed the maximum temperature in each segment – hot spot (HS). In each sector, it is individual and varies with the human moving.

Conclusion

In recent years much in the traditional approach to the design and production of special clothing has changed. More and more developers are trying to use a theoretically informed choice multilayer package clothing materials, taking into account the relationship between the structural and thermal parameters of materials, using different mathematical methods, such as regression modeling, optimization theory, computer technology. Taking into account all the effects of all the parameters and properties of the heat-shielding clothes is a difficult task, but the rational combination of layers of materials on the principle of unity and the coherence properties of the body provides reliable adaptation to changing conditions with light weight clothing.

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