TEXTILE MATERIALS MANUFACTURING FEATURES WITH THE USE OF ANTIMICROBIAL ADDITIVES

Olga Zhdanova, Sergey Bereznenko, Natalia Bereznenko and Dmitriy Novak

Kyiv National University of Technologies and Design, Nemyrovych-Danchenko St. 2, 01011 Kyiv, Ukraine
novak.knutd@gmail.com

Abstract: *We investigated the influence of modifiers on the processes of manufacturing of polypropylene (PP), polyethylene (PE) and polyoxymethylene (POM) yarns. We studied their influence on the physical-mechanical and microbiological properties concerning the most widespread pathogens of diseases. Shown the effect of modified yarns on the energy-information state of organs and systems of human organs and variational possibilities of creation of preventive health-giving materials on their basis were studied.*

Keywords: *modifiers, yarns, antimicrobial properties, pathogenic microflora, energy state of organs.*

1 INTRODUCTION

Some global trends prove that one of the long-range issues of the present time in the textile industry is the issue of new raw materials, textiles and clothing with due regard to the specific usage conditions. Especially it concerns professional clothes for extreme life conditions (critically ill and infected patients, hospital workers, athletes, etc.). In recent years so-called "smart materials" which contain modified natural fibers (flax, hemp, etc.) have been used extensively [1, 2]. They have a set of unique properties (low surface resistance, protection against ultraviolet radiation, antiseptic and hygroscopic properties) with acceptable levels of formaldehyde migration, toxic substances and radionuclides content. It encourages the production of medical, health-based and children's clothes.

However, there is a necessity to eliminate high creasing of textile materials with an increased content of bast fibers (50-70%) by combining them with synthetic components, including antimicrobial additives (AMA) (silver nanoproducts (Ag), copper (Cu), iron (Fe) and others).

This "hybridization" of properties for bast and synthetic components creates favourable conditions for manufacturing of products for various purposes. The properties of these products comply with OEKO-TEX® 100 international standards.

2 LITERATURE DATA ANALYSIS AND ARTICULATION OF ISSUE

In the modern society, people are involuntarily experiencing a growing influence of various factors (energy flows of internal and external origin, non-ionizing radiation), some types of drugs, pathogenic organisms (fungi, viruses, bacteria, intracellular parasites) on the human body. Under their influence, our organisms can change immune responses, spread and develop previously unknown types of diseases. A physical factor, such as pathogenic microflora, plays a dominant role in the emergence and development of many types of diseases.

The recent studies show that in the production of clothes for medical purposes (MP), the following factors should be considered:

- ethical, technogenic and ecological factors of human life support [1];
- features of microflora and its location in the human body as well as on the skin surface [2-4];
- specifics of distribution areas of hyperhidrosis (sweating) as one of the reasons for the reproduction of pathogenic organisms and creation of professional, social and psychological human deadaptation [5];
- energy-information aspect of the interaction between elements of the "man-clothes-environment" system in which clothes play a barrier role in relation to pathogenic organisms [6, 7].

In this regard, the role of clothes as a factor for suppression of harmful microflora and stimulation of beneficial microflora, including the biocide effect, is increasing significantly [8].

Antimicrobial finishing of textiles and other materials provide several functions:

- inhibition of reproduction and growth for colonies of microorganisms of the external origin;
- prevention of odors caused by waste products of microorganisms and protection of textile materials from destruction.

On the other hand, clothing materials are the source of self-energy emissions and provide a barrier function connected with the reflection or absorption of waves from pathogenic microflora and human body. This effect is achieved by interference, diffraction and resonance wave radiation from pathogenic components of textile materials and human body [9].

But the lack of information database about the features of formation of antimicrobic properties for polymeric materials by means of modifiers injection in their structure, the impact of the molding abilities of polymers on the manufacturing of yarns with protective properties requires further research in this area.

3 PURPOSE AND METHODS OF THE STUDY

The study was aimed to identify the features of the processes for injection of the AMA polymers into the structure and on their basis formation of yarns, which determine their suitability for further use in the manufacturing of textile and knitting materials for various purposes.

To achieve this goal the following tasks were done:

- to make initial selection of polymeric materials and determine the conditions of their injection into the structure of AMA;
- to examine the conditions of the fibers formation process for modified complex yarns and define the parameters of their formation on the existing equipment;
- to implement a comprehensive evaluation of antimicrobic, physical-mechanical properties of primary and composite yarns and define the area of their use;
- to identify the effectiveness of experimental samples influence on the functional state of organs and systems of the human body.

4 MATERIALS AND METHODS FOR THE INVESTIGATION OF IMPACT OF THE MODIFIES ON THE YARN FORMATION PROCESSES AND THEIR PROPERTIES

4.1 Materials and equipment that were used in the experiment

Impregnation of the yarns was carried out by completely placing of each sample in a solution of the antibacterial preparation, the impregnation time was 20 minutes, and the temperature of the solution was 20-24°C. After impregnation, the samples of the material were removed from the solution of the antibacterial preparation and dried in a suspended state without direct exposure of sunlight until dryness at temperature 22-26°C.

The following polymers were used in the study: polypropylene (PP) of A7 grade, polyethylene (PE) of 2112 grade, polyoxymethylene (POM), antimicrobial additives (AMA) - substituted diphenyl ether, suspensions and pastes based on Ag, Cu, Fe nanoparticles, surfactant active agent - polyethylene glycol (PEG 115). Production of complex yarns of PP and POM with AMA and nanocomposites was developed under laboratory technical regulations on the existing experimental equipment (laboratory extruder MSHG-00, machine for yarn formation MFGP, bench for drawing-out of yarn VSTV).

4.2 Methods to identify the features of sample properties

The research of physical-mechanical properties was carried out according to the current ISO and antimicrobial properties by death rates of the test plants and colony-forming organisms reduction (*S.aureus, E.coli, Calbicans, Candida*) (study carried out in cooperation with the State Research Institute «RESURS» and State Institution «Institute of Epidemiology and Infectious Diseases named after L. Gromashevsky» of the Academy of Medical Sciences of Ukraine, standard ASTM E 2149).

Energy-information assessment of nanomodified materials impact was performed on a software-based diagnostic system (HSDS) «Intera-Dia Cor», which is listed in the register of medical equipment in Ukraine No. 3227/2004 from 30.10.2009. According to the techniques used in the work [10], the indicators of energy stability, instability and coefficient of comfortability (CC) [11] were defined by the formula:

$$K_K = \frac{(K_C - K_H)}{K_C} \cdot 100\% \quad (1)$$

where K_c is total number of testing organs, K_H is the number of organs with negative changes.

5 RESULTS OF THE INVESTIGATION OF THE INDICATORS OF MODIFIED YARN SAMPLES PROPERTIES

The physical-mechanical properties prepared according to the technical specifications samples of polyfilamentous yarns modified by AMA and suspensions of Ag, Cu, and Fe nanoparticles (S/Z twist - 250/200, temperature of thermofixing for PE - 100°C, POM - 140°C). AMA were injected in the yarns in the formation process. The researched results showed that the preparation of yarns by AMA do not degrade the physical-mechanical properties (Table 1 and Table 2).

The minimum level of AMA (0.1 - 0.5%) used in the yarn structure, which effectively influences on microflora and does not reduce physical-mechanical properties, was investigated. Considering these data, the production of modified polypropylene yarns in different disperse environments was made (Table 2).

The data from Tables 1 and 2 show the possibilities for using POM and PP-based yarns in the practice of making clothes for medical purposes. With the simultaneous use of the modifiers of Ag, Cu and Fe nanocomponents in the different dispersed environments (pasta, alcohol, water).

Table 1 Physical-mechanical properties of yarns

Yarn No.	Type of yarn	Multiplicity of extension	The linear density [tex]	Breaking indicators		Tests in knot	
				Load [cN]	*Elongation [%]*	*Load [cN]*	*Elongation [%]*
1	POM	8.5	29.5	1836.0	12.1	884.0	5.5
2	POM + AMA	8.3	39.2	2009.0	14.7	961.5	7.0
3	PE	5.8	31.3	1568.0	24.6	1188.0	13.1
4	PE + AMA	5.3	33.3	1458.0	25.2	1196.0	15.1
5	PE	7.2	22.1	708.0	31.6	592.0	10.1
6	PE + AMA	5.0	33.2	520.0	15.6	515.0	15

Table 2 Physical-mechanical properties of nanomodified yarn

Yarn No.	The composition of the yarn	Disperse environment	Multiplicity of extension	The linear density [tex]	Breaking load [cN]	Relative breaking load [cN/tex]	Breaking elongation [%]
1	PP (original)	—	5.4	31.2	1122.0	36.0	20.6
	PEG 115 + Ag						
2	PP + 0.5%	paste	5.3	32.3	1066.0	33.7	28.3
3	PP + 1.0%	paste	5.3	31.1	1165.6	37.5	24.9
4	PP + 1.0%	alcohol	5.4	30.2	1161.2	38.4	18.1
	PEG 115 + Cu						
5	PP + 0.5%	paste	5.3	30.9	1132.8	36.7	20.5
6	PP + 1.0%	paste	5.3	32.0	1206.8	37.7	20.3
	PEG 115 + Ag + Cu						
7	PP + 0.5%	alcohol	5.3	32.6	1127.0	34.6	25.6
8	PP + 1.0%	alcohol	5.3	31.1	1134.4	36.5	19.2
	PEG 115 + Fe						
9	PP + 0.5%	water	4.3	45.5	1046.8	23.0	36.1
10	PP + 1.0%	water	5.4	32.6	1162.8	35.7	23.8

Microbiological studies have shown that yarns have prolonged antimicrobial properties concerning the test-cultures of *S.aureus, E.coli and Candida* (Table 3).
Efficiency of modified yarns in relation to the test cultures of *S.aureus* in terms of colony-forming organisms is also confirmed by the values of delay zones (3-5 mm) and exposure reduction (about 90% in 30 min.).

The results of additional studies show that yarns based on PP+AMA and POM+AMA are appropriate to use as the lower yarn lock-stitch and stitch. The sterilization of seams made with the use of such threads is not worse than the yarn of Coats-grail type that is used in the manufacturing of clothes.
Taking into account the positive test results of polyfilament yarns, the production of combined yarns with the use of cotton, linen and hemp components in their structure was made (Table 4).

Table 3 Antimicrobial properties of fibrous materials samples

The composition of fibrous material	Reduce of the test-cultures [%]					
	E.coli		***S.aureus***		***Candida***	
	Time of research [hours]					
	6	24	6	24	6	24
POM + 0.5% of AMA	58.4	61.4	40.0	53.4	76.9	89.0
PP + 0.5% of AMA	–	99.0	–	99.5	60.1	69.5

Table 4 Physical-mechanical properties of combined yarns

Yarn No	Type of yarn	The linear density [tex]	Temperature of thermofixation [°C]	Breaking indicators		Tests in knot	
				Load [cN]	Elongation [%]	Load [cN]	Elongation [%]
1	Cotton yarn + (POM + AMA)	84.5	140	1451.5	6.1	1435.6	6.0
2	Cotton yarn + (PP + AMA)	54.7	140	1877.2	5.1	1858.4	5.3
		77.2	140	1120.4	4.2	1257.2	4.5
		82.9	140	1422.4	5.5	1450.4	5.3
3	Mixed flaxen yarn + (POM + AMA)	82.5	110	1137.2	5.7	1152.0	5.7
4	Mixed flaxen yarn + (PP + AMA)	54.4	110	1877.2	5.4	1858.4	5.3
		81.0	110	1181.6	5.2	1017.5	4.9
		83.0	110	1309.6	6.0	1331.2	5.5
5	Mixed hemp yarn + (POM + AMD)	139.8	110	2853.2	12.2	2375.6	9.7

Considering that thermoplastic polymers usually contain various modifiers (plasticizers, stabilizers, antistatic agents, fungicides, etc.), they are injected into polymers in small amounts to improve their technological and operational properties. The studies have shown that the content of AMA more than 1.0% by weight is impractical and can cause the degradation processes of yarn formation and drawing-out. Therefore, in further studies, the quantitative indices of AMA were limited to 0.5-1.0% by weight, and the minimal suppressing concentration of AMA with *S.aureus* cultures and *Candida* fungi at the level of 0.05-0.1% by weight was confirmed by diffusion test in agar and by the method of serial dilution in Saburo broth. Moreover, the data presented in Table 1 show that PE yarns have 2 - 4 times less breaking load in comparison with PP and POM yarns, so their use in textile and knitwear sector may be limited, they can be used in the structure of knitted gasket materials as adhesive components [12], which is solving the problem of packing for clothing details by means of the thermal zone and provides protection from microbial environment, especially in the areas of increased sweating. In addition, this material provides the required level of shape stability. The second feature of the formation of the AMA yarn is their dependence on temperature thermofixation (for PE-based yarn it must not exceed 110°C). As for PP-based yarns, no significant changes in the breaking load and breaking elongation at the fixation of temperature from 20 to 140°C occur, which is evidently caused by relaxation processes in filaments on rigid packaging. However, it must be noted that the type of dispersion environment (Table 2) does not significantly affect the physical and mechanical properties of modified yarns and they can be used in garment, textile, hosiery industries and hospital practice as retention sutures. The studies have shown that it is possible to expand the range of application for such yarns by combining them with linen, hemp, and cotton components (Table 4). Firstly, the technology of the production of yarns from the short fibrous fractions of flax and hemp [13], developed at the University, makes it possible to use their inherent antimicrobial properties in medicine and the related areas. It is possible to create yarns with a wide range of total linear density, which defines the area of their wide application (fabric, knitted fabric, artificial fur, combined products) (Figure 1).

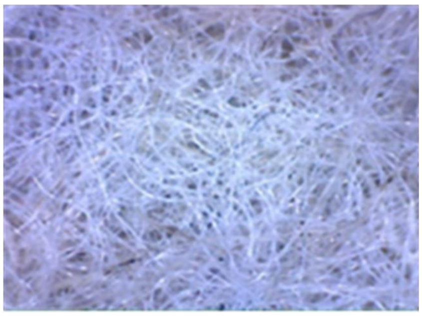
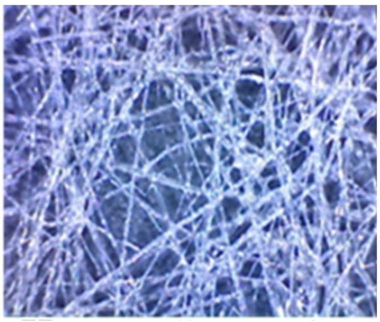
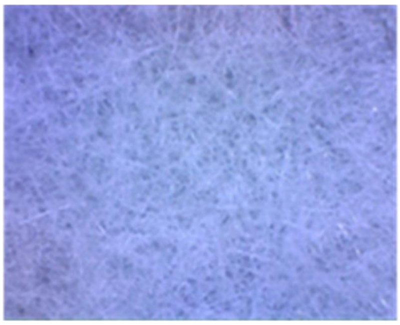
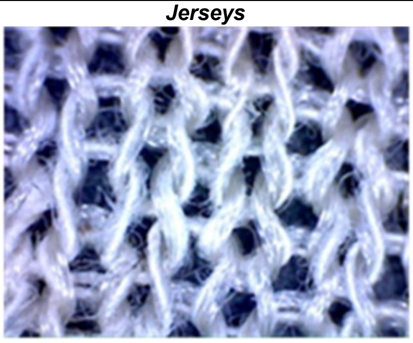
Nonwoven materials		
		
70% of hemp 15% of lavsan 14% of PEG (fusible) 1% of PEG + 0.4% Ag	70% of PP 29.5% of PE (fusible) 0.5% of PEG + 0.4 % Ag	99.5% of PP 0.5% of PEG +0.4% Cu
Jerseys	***Fur on textile basis***	***Compression products***
		
40% of linen 40% of cotton 20% of PP + 0.4% Ag	40% of hemp 50% of wool 10% of PP (base) +0.4% Ag	55% of linen 31% of lycra 14% of PP (base) + 0.4% Ag

Figure 1 Nanomodified textile materials

The microbiological research showed that the abovementioned materials (Table 5) have sufficient antibacterial and fungicidal properties.

These data show a sustained impact of modifiers on pathogenic components. The effectiveness of such an action of modifiers was also confirmed in the processing of domestic assortment fabrics by impregnation and surface aerodynamic and spraying of Ag and Cu nanoparticles (zone growth retardation of *S.aureus* and *C.albicans* was 4-12 mm).

The positive research results open perspectives of this technology in the production of clothes for medical and recreational purposes directly in terms of garment production.

It is also possible to expand the range of properties of nanomodified materials due to the inclusion of current-conducting components in their structure [14].

Testing of the created materials was performed at the "Intera-Dia Cor" complex. They found a positive influence of the nanomodification materials on the functional state of organs and systems of human organs. It was proved by the testing data of nanomodified cotton fabric with a drug based on Ag particles (Figure 2).

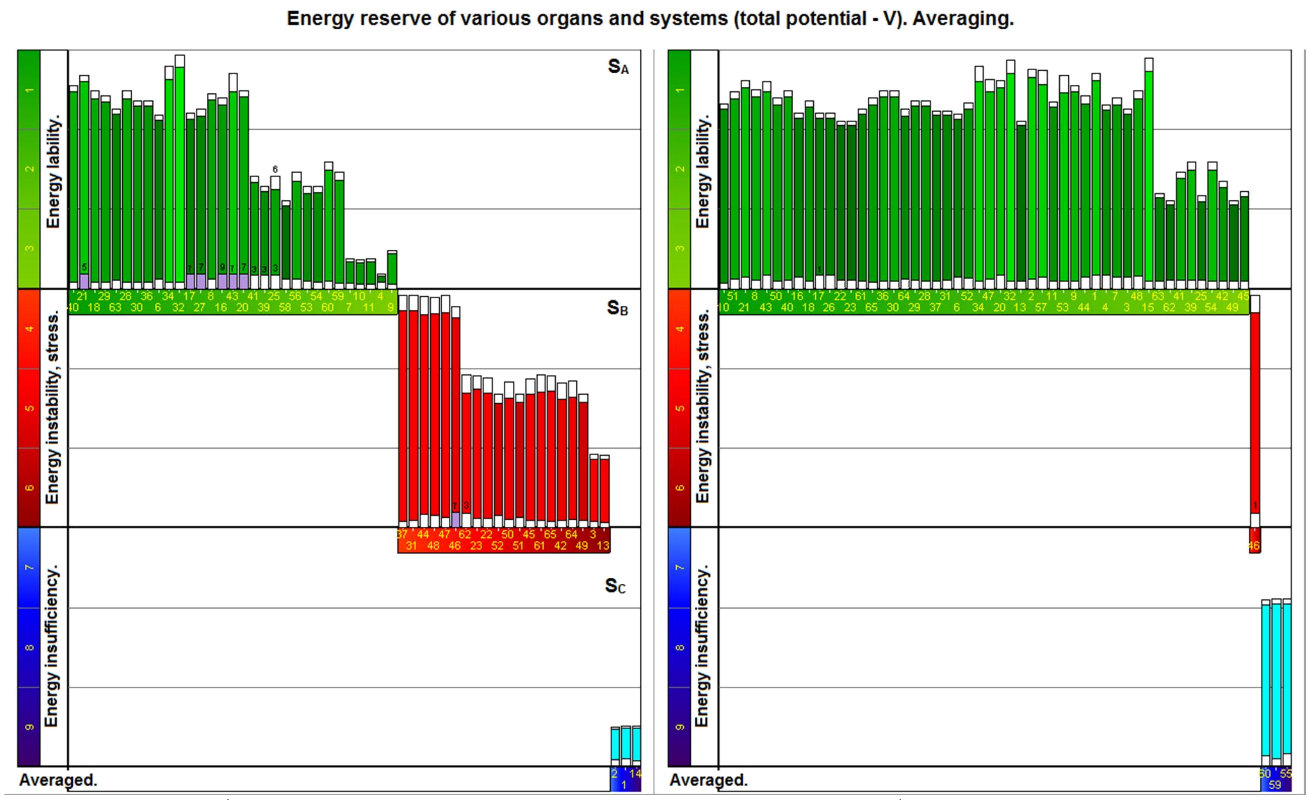
As it can be seen from the diagrams above, using nanomodified materials the indicators of the stable state can be increased significantly, due to the transition of 19 organs from an unstable to a stable state.

In addition, the individual approach to the choice of textile materials for clothes of health and preventive purposes was set. This is confirmed by the level of comfort that was within 51.4-97.4% for the 4 tested persons.

Table 5 Indicators of antibacterial and fungicidal properties of textile materials

Commodity composition	The inhibition zone [mm]	Quantity of microorganisms during the exposure											
		S.aureus				*E.coli*				*C.albicans*			
		Time of research [hours]											
		1	3	6	24	1	3	6	24	1	3	6	24
Cotton *	3	1	3	6	24	1	3	6	24	1	3	6	24
Linseed (Jersey)	3-4	133	1	0	0	4200	2	0	0	HB	0	HB	0
Non-woven PP material	4-5	44	0	0	0	822	750	430	0	-	-	-	-

Note: *-modified by the method of spraying suspension based on PEG + 0.5% Ag



a) without the material b) with the material

Figure 2 The results of the diagnosis of the functional state of organs of the tested person: S_A - stable; S_B - unstable; S_C -insufficient.

6 CONCLUSION

The findings concerning the creation of materials and products for medical and preventive purposes were generalized. The technology for manufacturing of experimental yarn samples using polymeric materials modified by antimicrobic products (AMA, suspensions and pastes with a content of 0.5-1.0% Ag, Cu, Fe) was developed. Energy-information and antimicrobial properties of textile materials in relation to pathogenic microflora were determined. The experimental samples of fabrics, knitwear, non-woven materials using the most effective modifiers were established. The received data give the basis to estimate prospects of a wider use of innovative materials with the attached antimicrobial properties at the production of protective clothes for various purposes.

7 REFERENCES

1. Bereznenko N.P., Yantsalovsky A.I., Vlasenko V.I., Lishchuk V.I.: Ecological and ethical aspect of the creation and use of nanomodified textile materials in products with preventive and medical purpose, In: 5th National Congress on Bioethics, Kyiv, 23-25.09, 2013, p. 106
2. Lukichev N.L.: Electropunctural diagnostic, homeopathy, and the phenomenon of long-range, M., Mosgorpechat, 1990, p. 136
3. Bacterial map of the body [electronic resourse] – Mode of access: https://www.gazeta.ru/science/2009/05/30_a_3181566.shtml
4. Diseases of the scalp - dermatological, fungal, pustular, infectious [electronic resource] – Mode of access: http://momandkids.net.ua/xvoroby-mamy-i-tata/3269-zaxvoryvana-chkiry-golovy.html
5. Head sweating: causes and methods of dealing with it [electronic resource] – Mode of access: http://amlima.com/vagitnist/1558-pitlivist-golovi-prichini-i-metodi-borotbi-z-neju.html
6. Fedotkin I.M.: Notes on the theory of information-wave medicine, Kiev, Publisher "Himgest", 2003, p. 43
7. Bereznenko M.P., Fedotkin I.M. Yantsalovsky I.M., Bereznenko S.M.: The role of clothing as a factor in health nature, Bulletin of KNU No. 3, 2013, pp. 16-19
8. Bereznenko M., Pawłowa M., Bereznenko S., Wlasenko V., Kurlowa N.: Synthetic threads modified with metal nanopreparations, Towaroznawcze problemy jakosci, Polish journal of commodity science, Radom 3(28), 2011, pp. 20-125
9. Luchko L.G.: Multidimensional medicine. The system of self-healing, Moscow: ANO "Publishing house", 2001, p. 432
10. Patent No. 35944, IPC G01N33/36. A method of evaluating the comfort of textile materials, Lucshevska O.M., Yantsalovsky O.Y., Trojan O.M.; applicant and patent holder Khmelnitsky National University – No. 200805703; Appl. 30.04.08; Publ. 10.10.2008, Bulletin. No. 19, p. 4
11. Lucshevska O.M., Trojan O.M.: Development of comfort methodology of textile materials research, Bulletin of KNU No. 6, 2008, pp. 151-155
12. Makhinya T.O., Kotova G.M., Bereznenko M.P. Zubovich L.A., Romankevich O.V.: Knitted cushioning material, Patent for the invention YA from 21885 from 30.04.1998. Bull. No. 2.
13. Bereznenko M.P., Bereznenko S.M., Khokhlova I.Ja., Korostenko S.M.: Thread wrapping: the patent for the invention of YA 60720 from 16.05.2005, Bull. No. 5
14. Novak D., Budash Y., Bereznenko N.: Graphic modeling of conductive filler spatial distribution in polymer matrix, Vlakna a textil (Fibres and Textiles) 23(2), 2016, pp. 37-42