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DETERMINING PARAMETERS OF ELECTROMAGNETIC RADIATION FOR ENERGOINFORMATIONAL DISINFECTION OF WOOL IN ITS PRETREATMENT

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Пригнічення інфекційних мікроорганізмів у кіпках вовни можливо за допомогою електромагнітного випромінювання (ЕМВ) з параметрами: частота 36 ГГц, потужність 0,5 кВт, експозиція 3 хв. Енергоінформаційні параметри були визначені в результаті теоретичних і експериментальних досліджень процесу взаємодії ЕМВ з інфекційними мікроорганізмами

Ключові слова: електромагнітне випромінювання міліметрового діапазону, інфекційні мікроорганізми, біотропні параметри, дезінфекція шерсті

Угнетение инфекционных микроорганизмов в кипках шерсти возможно при помощи электромагнитного излучения (ЭМИ) с параметрами: частота 36 ГГц, мощность 0,5 кВт, экспозиция 3 мин. Энергоинформационные параметры были определены в результате теоретических и экспериментальных исследований процесса взаимодействия ЭМИ с инфекционными микроорганизмами

Ключевые слова: электромагнитное излучение миллиметрового диапазона, инфекционные микроорганизмы, биотропные параметры, дезинфекция шерсти

1. Introduction

Due to many of its qualities, wool is an indispensable fiber for production of textiles. The ability to retain warmth and moisture, high strength and elasticity, lightness and good spinning ability distinguish wool from flax and synthetic fibers. Wool is indispensable in the manufacture of outerwear and knitwear, which is important for the population of countries with a sharply continental climate.

Preservation of competitive positions of wool in the market of textile materials is largely determined by its quality. Quality of wool fiber depends on its pretreatment. One of the primary tasks in the treatment of wool is its disinfection in the technological process of classifying and sorting. Analysis of the technological process and equipment used by wool processing enterprises has revealed their significant shortcomings [1–5]:

- in the process of classifying and sorting, the natural properties of wool are destroyed and only 10 % of wool meets standard requirements;

- the use of formalin and phenol vapors and solutions reduces breaking load and strength of wool up to 20 %;

- the use of chemicals for disinfection of wool adversely affects environment;

- warming up wool with steam requires a lot of energy and promotes reproduction of pathogenic microorganisms.

In this connection, there is a need of theoretical and experimental study of the regularities observed in the effect of electromagnetic energy on pathogenic microorganisms in wool, which is relevant at the moment.

2. Literature review and problem statement

The main task in the classification of wool is its disinfection with maximum preservation of its natural properties. It has been established that 1 g of wool contains 400 to 700 million bacteria [2].

Based on the bacterial flora studies, it was found that air contains 300 to 13,920 colonies of staphylococci and 30 to 5,710 colonies of streptococci in 1 m² [3].

Thus, in order to reduce disease incidence of classifiers and sorters, it is necessary to use wool disinfection during its preprocessing.

Currently, effective methods of wool disinfection consist in using steam-formalin chambers, Krupin's chambers and a method for washing wool with formalin [4]. In addition, the method of wool disinfection by extracting with solvents containing some reagents is of interest [5].

However, the use of chemical disinfectants for destruction of pathogenic microorganisms in wool is associated with significant labor costs, time, and their influence on fiber quality, human organism and environment [6].

All of the above requires development of a new technology for processing wool on a fundamentally new basis [7].

As analysis shows, for destruction of pathogenic microorganisms in wool, preservation of the wool fiber quality and environmental protection, it is necessary to use electromagnetic (EM) methods of wool disinfection. The use of EM energy for disinfection of wool will shorten technological process, improve sanitary and hygienic working conditions, and boost labor productivity [8].

However, creation of EM technology and an electronic system for wool disinfection requires both theoretical and experimental studies.

3. The objective and tasks of the study

This work's objective is the development of an electromagnetic method applicable in the millimeter wavelength range and determination of biotrophic parameters of electromagnetic fields for disinfection of pathogenic microorganisms in bales of wool in the technological process of its processing.

To achieve this objective, it was necessary to solve the following tasks:

- develop a model of interaction between low-energy EMF in the millimeter wavelength range and pathogenic microorganisms in wool;
- based on the theoretical analysis of this model, determine the scope of changes in the biotrophic parameters of EMF ensuring destruction of pathogenic microorganisms in wool;
- carry out experimental studies on disinfection of wool with EMF energy of the millimeter wavelength band.

4. Theoretical analysis of interaction between electromagnetic radiation and pathogenic microorganisms in sheep wool

Let the EM wave fall on the ellipsoidal body of pathogenic microorganisms (staphylococci, streptococci, Escherichia coli, etc.) having two layers. The outer layer number 1 is characterized by dielectric and magnetic permeabilities ϵ_1 , μ_0 and the layer number 2 is characterized by dielectric and magnetic permeabilities ϵ_2 , μ_0 . Medium has dielectric permeability ϵ_0 and magnetic permeability μ_0 .

If the surface of the inner layer 2 is described by the following equation:

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} + \frac{z^2}{c^2} = 1, \quad (1)$$

then, considering the surfaces of the second and the first layers to be equipotential, the following is true for the first layer:

$$\frac{x^2}{a^2(1+\xi_1)} + \frac{y^2}{b^2(1+\xi_1)} + \frac{z^2}{c^2(1+\xi_1)} = 1, \quad (2)$$

where ξ_1 is the constant relating dimensions of the second layer semi-axes with dimensions of the first layer semi-axes.

Obviously, the incident field will excite an internal field in the first layer which in turn will induce a field in layer 2. However, EMF in layer 2 will bring about appearance of a wave scattered in the near zone in layer 1. Thus, the field in layer 1 can be expressed as follows:

$$\vec{E}^1 = \vec{E}_{inc}^1 + \vec{E}_{rfl}^1, \quad (3)$$

in layer 2:

$$\vec{E}^2 = \vec{E}_{rfl}^2. \quad (4)$$

Here symbol 'inc.' marks the fields excited inside the layer by EM waves that are external relative to these fields, symbol 'rfl.' marks the fields caused by scattering in the inner layer.

To write the summands in (3), (4) with the index 'inc.', use the result of work [9]:

$$\begin{aligned} \vec{E}_{rfl}^{(0)1} &= \frac{A_1}{\Delta_1} \vec{E}_0^{(0)}, \\ \vec{E}_{rfl}^{(0)2} &= \frac{A_2}{\Delta_2} \vec{E}_0^{(0)}, \end{aligned} \quad (5)$$

where A_1 is a matrix equal to:

$$\begin{vmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{vmatrix}. \quad (6)$$

The matrix elements are defined by the following expressions:

$$\begin{aligned} a_{11} &= 1 + \left(\frac{\epsilon_1}{\epsilon_0} - 1 \right) \frac{abc}{2} (I_2 + I_3) - \left(\frac{2\epsilon_1}{\epsilon_0} - 1 \right) \left(\frac{abc}{2} \right)^2 I_2 I_3; \\ a_{12} &= -\frac{\epsilon_1}{\epsilon_0} \left(\frac{abc}{2} \right)^2 I_1 (I_1 + I_2); \\ a_{13} &= -\frac{\epsilon_1}{\epsilon_0} \left(\frac{abc}{2} \right)^2 I_1 (I_1 + I_3); \\ a_{21} &= -\frac{\epsilon_1}{\epsilon_0} \left(\frac{abc}{2} \right)^2 I_2 (I_1 + I_2); \\ a_{22} &= 1 + \left(\frac{\epsilon_1}{\epsilon_0} - 1 \right) \frac{abc}{2} (I_1 + I_3) - \left(\frac{2\epsilon_1}{\epsilon_0} - 1 \right) \left(\frac{abc}{2} \right)^2 I_1 I_3; \\ a_{23} &= -\frac{\epsilon_1}{\epsilon_0} \left(\frac{abc}{2} \right)^2 I_2 (I_2 + I_3); \\ a_{31} &= -\frac{\epsilon_1}{\epsilon_0} \left(\frac{abc}{2} \right)^2 I_3 (I_1 + I_3); \\ a_{32} &= -\frac{\epsilon_1}{\epsilon_0} \left(\frac{abc}{2} \right)^2 I_3 (I_2 + I_3); \\ a_{33} &= 1 + \left(\frac{\epsilon_1}{\epsilon_0} - 1 \right) \frac{abc}{2} (I_1 + I_2) - \left(\frac{2\epsilon_1}{\epsilon_0} - 1 \right) \left(\frac{abc}{2} \right)^2 I_1 I_2. \end{aligned} \quad (7)$$

$$\begin{aligned} \Delta_1 &= \frac{\epsilon_1}{\epsilon_0} - \left(\frac{2\epsilon_1}{\epsilon_0} - 1 \right) \left(\frac{abc}{2} \right)^2 (I_1 I_2 + I_1 I_3 + I_2 I_3) + \\ &+ \left(\frac{3\epsilon_1}{\epsilon_0} - 1 \right) \left(\frac{abc}{2} \right)^3 I_1 I_2 I_3; \\ \Delta_{1x} &= \left[1 + \left(\frac{\epsilon_1}{\epsilon_0} - 1 \right) \frac{abc}{2} (I_2 + I_3) - \left(\frac{2\epsilon_1}{\epsilon_0} - 1 \right) \left(\frac{abc}{2} \right)^2 I_2 I_3 \right] E_{0x}^{(0)} - \\ &- \frac{\epsilon_1}{\epsilon_0} \left(\frac{abc}{2} \right)^2 I_1 (I_1 + I_2) E_{0y}^{(0)} - \frac{\epsilon_1}{\epsilon_0} \left(\frac{abc}{2} \right)^2 I_1 (I_1 + I_3) E_{0z}^{(0)}; \\ \Delta_{1y} &= - \frac{\epsilon_1}{\epsilon_0} \left(\frac{abc}{2} \right)^2 I_2 (I_1 + I_2) E_{0x}^{(0)} + \left[1 + \left(\frac{\epsilon_1}{\epsilon_0} - 1 \right) \frac{abc}{2} (I_1 + I_3) - \right. \\ &- \left. \left(\frac{2\epsilon_1}{\epsilon_0} - 1 \right) \left(\frac{abc}{2} \right)^2 I_1 I_3 \right] E_{0y}^{(0)} - \frac{\epsilon_1}{\epsilon_0} \left(\frac{abc}{2} \right)^2 I_2 (I_2 + I_3) E_{0z}^{(0)}; \\ \Delta_{1z} &= - \frac{\epsilon_1}{\epsilon_0} \left(\frac{abc}{2} \right)^2 I_3 (I_1 + I_3) E_{0x}^{(0)} - \\ &- \frac{\epsilon_1}{\epsilon_0} \left(\frac{abc}{2} \right)^2 I_3 (I_2 + I_3) E_{0y}^{(0)} + \\ &+ \left[1 + \left(\frac{\epsilon_1}{\epsilon_0} - 1 \right) \frac{abc}{2} (I_1 + I_2) - \left(\frac{2\epsilon_1}{\epsilon_0} - 1 \right) \left(\frac{abc}{2} \right)^2 I_1 I_2 \right] E_{0z}^{(0)}. \end{aligned} \quad (8)$$

where a, b, c are dimensions of the ellipsoid semi-axes; I_1, I_2, I_3 are constants expressed in terms of elliptic integrals:

$$\begin{aligned} I_1 &= \int_0^{\infty} \frac{ds}{(a^2 + s)R(s)}, \quad I_2 = \int_0^{\infty} \frac{ds}{(b^2 + s)R(s)}, \\ I_3 &= \int_0^{\infty} \frac{ds}{(c^2 + s)R(s)}, \quad R(s) = \sqrt{(a^2 + s)(b^2 + s)(c^2 + s)}. \end{aligned} \quad (9)$$

For Δ_2 , it is necessary to substitute ϵ_2 for ϵ and substitute ϵ_1 for ϵ_0 in formula (7). Similar substitutions are made in (8) to obtain Δ_2 .

The field $\vec{E}_{inc}^{(0)l}$ is found from [9]:

$$\vec{E}_{inc}^{(0)l} = \frac{A_2}{4\pi\Delta_2} \left(\frac{\epsilon_2}{\epsilon_1} - 1 \right) \hat{P} \vec{E}^{(0)l} W_1'. \quad (10)$$

The substitution of (5), (10) into (3), (4) results in a linear system of two equations with two unknowns $\vec{E}^{(0)l}, \vec{E}^{(0)2}$:

$$\begin{cases} \vec{E}^{(0)l} = \frac{A_1}{\Delta_1} \vec{E}_0^{(0)} + \frac{A_2}{4\pi\Delta_2} \left(\frac{\epsilon_2}{\epsilon_1} - 1 \right) \hat{P} \vec{E}^{(0)l} W_1'; \\ \vec{E}^{(0)2} = \frac{A_2}{\Delta_2} \vec{E}^{(0)l}. \end{cases} \quad (11)$$

Write the system in a somewhat different way:

$$\begin{cases} \left[1 - \frac{A_2}{4\pi\Delta_2} \left(\frac{\epsilon_2}{\epsilon_1} - 1 \right) \hat{P} W_1' \right] \vec{E}^{(0)l} = \frac{A_1}{\Delta_1} \vec{E}_0^{(0)}; \\ - \frac{A_2}{\Delta_2} \vec{E}^{(0)l} + \vec{E}^{(0)2} = 0. \end{cases} \quad (12)$$

This system is a square heterogeneous system. Consequently, it has a unique solution if its determinant is different from zero. Making calculations, it is easy to make sure that this is indeed the case.

Solution of system (12) is easy to find expressing $\vec{E}^{(0)l}$ from the first equation, and then by finding $\vec{E}^{(0)2}$ from the second equation. For brevity, denote the matrix:

$$E - \frac{A_2}{4\pi\Delta_2} \left(\frac{\epsilon_2}{\epsilon_1} - 1 \right) \hat{P} W_1' = B_1, \quad (13)$$

where E is the unit matrix of the same order as A.

Then from the first equation of system (12):

$$B_1 \vec{E}^{(0)l} = \frac{A_1}{\Delta_1} \vec{E}_0^{(0)},$$

it follows that:

$$\vec{E}^{(0)l} = B_1^{-1} \frac{A_1}{\Delta_1} \vec{E}_0^{(0)}. \quad (14)$$

From the second equation:

$$\vec{E}^{(0)2} = \frac{A_2}{\Delta_2} \vec{E}^{(0)l}$$

obtain:

$$\vec{E}^{(0)2} = \frac{A_2}{\Delta_2} B_1^{-1} \frac{A_1}{\Delta_1} \vec{E}_0^{(0)}. \quad (15)$$

Here B_1^{-1} is the matrix inverse to the matrix B_1 . The results were obtained using the method of solving matrix equations and matrix multiplication in (14), (15) must be performed in the order in which they stand in the formulas.

5. Determining the magnitude of the electric field strength and the induced potential on the membrane of pathogenic organisms

The obtained expressions (14), (15) make it possible to estimate dependence of the jump of the electric field intensity between the inner part of the pathogenic microorganism present in the wool and its coating which is approximately 0.005 μm thick, that is (Fig. 1)

$$E = \left| \vec{E}_2^{(0)} - \vec{E}_1^{(0)} \right|.$$

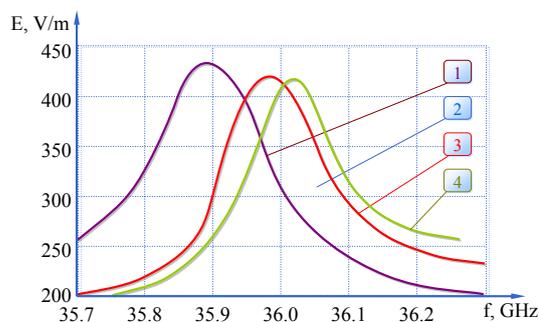


Fig. 1. Dependence of EF strength jump between external coat and interior of pathogenic microorganisms in wool on the dropping EMF frequency for a variety of microorganism linear dimensions: 1 – $l=8 \mu\text{m}; d=1.5 \mu\text{m}$; 2 – $l=6 \mu\text{m}, d=2 \mu\text{m}$; 3 – $l=3 \mu\text{m}; d=0.6 \mu\text{m}$; 4 – $l=1.5 \mu\text{m}; d=1 \mu\text{m}$

The data on electrophysical characteristics of microorganism tissues, viz., DC, loss tangent, etc. were taken from the reference book [10].

As follows from the graph (Fig. 1), the maximum jump in the intensity of the EF at the boundary between the coating and the interior of the microorganism changes its position by frequency depending on the sizes of the microorganisms in the wool. The lowest frequency at this maximum was for the pest length of 8 μm and diameter of 1.5 μm. The highest frequency at the maximum is for length of 1.5 μm and diameter of 1 μm. The values of the maxima themselves practically do not change for different sizes of microorganisms and lie in the range 425...430 V/m. The different width of the resonance curves can be explained by the different relationship between the length and diameter of the microorganisms. The jumps themselves are explained by the suppression of EMF inside the first layer due to addition of the past and reflected fields with different phases.

However, it is difficult to conclude from the obtained result what damages in the body of microorganisms can cause such a jump of EP intensity. The answer to this question can only be given by information on a possible electrical breakdown of the microorganism membrane.

$$\varphi = \sqrt{\varphi_0^2 + P \frac{C_0 V_0 q^2 C_s}{(4\pi\epsilon\epsilon_0 d)^2} te^{\frac{F\varphi_0 q}{kT e}} + P \frac{qC_s}{4\pi\epsilon\epsilon_0 \omega} E \sin \omega t}, \quad (16)$$

where φ is the potential at the boundary between the coating and the interior of microorganisms during their exposure to EMF; φ_0 is the potential at the boundary of these layers in the norm; p is the permeability of microorganism cell membranes in wool; C_0 is the average concentration of non-penetrating substance inside the cells at the initial time; V_0 is the average volume of a pathogenic microorganism body; q is the ion charge; e is the electron charge; C_s is the concentration of the penetrant; ϵ_1 is complex relative DC of coating of the pathogenic microorganisms; ϵ_0 is DC of free space; d is thickness of the microorganism coating; F is the Faraday number; R is the gas constant; T is absolute temperature; t is the exposure time; ω is the angular frequency of EMF, which affects the pathogenic microorganisms; E is the jump in intensity of the electrical component of the incident EMF at the boundary between the microorganism coating and its interior.

As is known, in the natural state, there is a potential of the order of 80...100 mV on the cell membrane associated with the transport of ions through it [11]. This potential does not cause damage to the membrane and regulates metabolism proceeding through it. Increase in this potential to 150...160 mV results in a breakdown of membrane and its destruction. Thus, existence of potentials of the order of 150 mV at the boundary between the coating and the body of a pathogenic microorganism, which can cause an external EM effect will bring about death of the microorganism in the wool.

The results of this calculation are shown in Fig. 2 where the exposure time is constant and equal to 0.001 s.

As follows from the graph (Fig. 2), magnitude of the induced potential at the mycobacteria membrane is 0.15 V, which is enough to destroy the membrane. This result confirms the conclusion that it is necessary to use EMF with frequencies of the order of 35.9...36 GHz. The above expression (16) also makes it possible to determine an optimum

exposure time for destruction of pathogenic microorganisms in wool by external EM radiation. Dependence of the induced potential φ on the exposure time t at a constant EM frequency of 35.95 GHz and a constant power flux density of 1.25 mW/cm² is shown in Fig. 3.

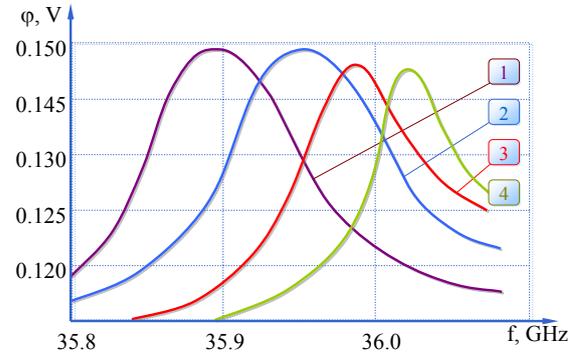


Fig. 2. Dependence of the induced potential φ at the boundary between the coating and the body of pathogenic microorganisms present in wool on the EMF frequency under constant exposure time $t = 0.001$ s for various linear dimensions: 1 – $l=8$ μm; $d=1.5$ μm; 2 – $l=6$ μm; $d=2$ μm; 3 – $l=3$ μm; $d=0.6$ μm; 4 – 1.5 μm; $d=1$ μm

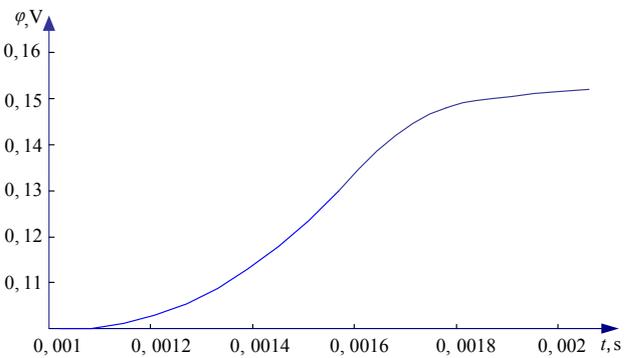


Fig. 3. Dependence of the induced potential φ at the boundary between the coating and the body of pathogenic microorganisms in wool on the exposure time at a constant frequency of 35.95 GHz and a power flux density of 1.25 mW/cm²

Analysis of the obtained numerical results shows (Fig. 3) that as the time increases to 0.0018 s, potential grows and reaches its maximum value. At an exposure value of the order of 0.0018 s, the potential maximum at the boundary reaches 0.15 V, which is sufficient for breakdown of membrane of the pathogenic microorganism and its death.

6. Experimental application of electromagnetic radiation for wool disinfection

The objective of experimental tests was to determine dependence of the number of microbiological objects in wool and wool temperature on the exposure time and power of electromagnetic radiation at a frequency of 36 GHz.

The tests have shown that treatment of wool bales by applying EMF with parameters given in Table 1 led to de-

struction of most microorganisms in wool and decreased their number. Temperature in the wool bale was only 15 °C at such parameters of EMF.

Cutting the time of EMF irradiation of the baled wool to 60 s at the DRO power source of 0.5 kW also did not lead to a complete destruction of microorganisms in wool and temperature increased by 8 °C (Table 2).

Irradiation of the baled wool with EMF parameters (frequency, power, exposure time) 36 GHz, 0.5 kW, 3 min has led to a complete destruction of microorganisms in wool and temperature growth was as high as 38 °C.

Effect of EM energy in the millimeter wavelength range on breaking load and relative strength of wool during its processing by electromagnetic energy was studied in this experiment. Washed and unwashed semi-thin wool was taken for the experiment.

In control runs for the unwashed wool, breaking load was 805.3 cN and relative strength was 4.96 cN/tex. In control runs for the washed wool, breaking load was 734.5 cN and the relative strength was 3.3 cN/tex.

7. Discussion of the results obtained in the study of wool disinfection with EMF

To solve the assigned task, a quasi-static approach was applied in the work which assumes that the electric field amplitude is constant inside pathogenic microorganisms. This is connected with the fact that the pathogenic microorgan-

isms in wool have the shape of an elongated ellipsoid with its length a within 1.5...8 μm and diameter b within 0.6...2 μm. Hence, the incident wave has a length much greater than the linear dimensions of the pests.

As a result of theoretical studies, the obtained expressions (14) and (15) allowed not only to estimate magnitude of intensity of the EMF electrical component but also to determine the jump of this intensity on the microorganism surface. First, the dependence of the EF intensity jump between the inner part of the pathogenic microorganism in wool and its coating having thickness about 0.005 μm, i. e.

$$E = \left| \vec{E}_2^{(0)} - \vec{E}_1^{(0)} \right|,$$

on the frequency *f* of the EMF acting on it was studied. Calculations were carried out for various sizes of microorganisms, and it was found that these dimensions practically did not affect the magnitude of the intensity jump. As follows from the graphs (Figs. 1–3), the maximum EF intensity jump at the boundary between the coating of the microorganism and its interior changes its position by frequency depending on the sizes of the microorganisms in wool. The lowest frequency at this maximum was for the pests with length 8 μm and diameter 1.5 μm and the highest was for the pests with length 1.5 μm and diameter 1 μm. In this case, the intensity jump maxima themselves changed their position from the incident field frequency of 35.9 GHz to the frequency of 36.025 GHz.

The results of the studies on wool disinfection are given in Tables 1–3.

Table 1

Results of microbiological examination of baled wool during its disinfection and warming by EM energy at a frequency of 36 GHz, exposure time of 180 s and SHF power of 0.25 kW

No.	Microorganisms secured in control runs	EHF exposure time, s	EHF radiation power, kW	Temperature in wool bale, ΔT, °C	Number of microorganisms in the days after inoculation			Types of microorganisms secured in the days after inoculation		
					2 nd day	3 rd day	4 th day	2 nd day	3 rd day	4 th day
1	Staphylococcus Enterococcus	180	0.25	15	1250	1025	928	+	+	-
2	Bacillus subtilis							-	-	-
3	Cereus							-	-	-
4	Yeast cells							-	-	-
5	Tetrococcus							-	-	-
6	Sporozoa							+	+	+
7	Coli bacillus							-	-	-
8	Staphylococcal epidermidis							-	-	-
9	Golden staphylococcus							+	+	+

Note: “+” – presence of microorganisms; “-” – absence of microorganisms

Table 2

Results of microbiological examination of baled wool during its disinfection and warming by EM energy in the millimeter wavelength range

No.	Microorganisms secured in control runs	EHF exposure time, s	EHF radiation power, kW	Temperature in wool bale, ΔT, °C	Number of microorganisms in the days after inoculation			Types of microorganisms secured in the days after inoculation		
					2 nd day	3 rd day	4 th day	2 nd day	3 rd day	4 th day
1	Staphylococcus Enterococcus	60	0.5	8	1700	1525	1225	+	+	-
2	Bacillus subtilis							-	-	-
3	Cereus							-	-	-
4	Yeast cells							-	-	-
5	Tetrococcus							-	-	-
6	Sporozoa							+	+	+
7	Coli bacillus							-	-	-
8	Staphylococcal epidermidis							-	-	-
9	Golden staphylococcus							+	+	+

Note: "+" – presence of microorganisms; "-" – absence of microorganisms

Table 3

Results of microbiological examination of baled wool during its disinfection and warming by EM energy at a frequency of 36 GHz, exposure time of 180 s and SHF power of 0.5 kW

No.	Microorganisms secured in control runs	EHF exposure time, s	EHF radiation power, kW	Temperature in wool bale ΔT, °C	Number of microorganisms in the days after inoculation			Types of microorganisms secured in the days after inoculation		
					2 nd day	3 rd day	4 th day	2 nd day	3 rd day	4 th day
1	Staphylococcus Enterococcus	180	0.5	38	-	-	-	-	-	-
2	Bacillus subtilis							-	-	-
3	Cereus							-	-	-
4	Yeast cells							-	-	-
5	Tetrococcus							-	-	-
6	Sporozoa							-	-	-
7	Coli bacillus							-	-	-
8	Staphylococcal epidermidis							-	-	-
9	Golden staphylococcus							-	-	-

Note: "+" – presence of microorganisms; "-" – absence of microorganisms

However, it is difficult to conclude from the obtained result given in Tables 1–3 what damage in the microorganism bodies could be caused by such a jump in the EF intensity. The answer to this question can only give information on the possible electrical breakdown of the microorganism membrane.

To obtain such information, an expression was used that relates the potential on the cell membrane with its physico-

chemical parameters, incident EMF intensity and this field frequency.

As is known, there is a potential of the order of 80...100 mV on the cell membrane in a natural state. This potential is connected with the transport of ions through it. It does not damage the membrane and regulates the metabolism through the membrane. Increase in this potential to 150...160 mV results in breakdown of the membrane and its destruction.

Experimental studies of EMF irradiation of wool bales were performed at the following parameters (frequency, power, exposure time): 36 GHz; 0.5 kW, 3 min. Such parameters brought about complete destruction of microorganisms in wool and temperature growth by 38 °C (Table 3).

During the experiment, influence of the EM energy of the millimeter wavelength range on breaking load and relative strength of wool during its treatment by electromagnetic energy was investigated. Washed and unwashed semithin wool was taken for the experiment.

Unwashed and washed wool was exposed to EMF with the following parameters (frequency, power, exposure time): 36 GHz, 0.5 kW, 3 min. In this case, an increase in breaking load of 200...300 cN was observed and the relative strength was improved by 2...3 cN/tex. In control runs for unwashed wool, breaking load was 805.3 cN and relative strength was 4.96 cN/tex. For washed wool, breaking load was 734.5 cN, and relative strength was 3.3 cN/tex. in the control runs.

Analysis shows that to destroy pathogenic organisms in wool while preserving the wool fiber quality and en-

vironment, it is necessary to apply EM methods of wool disinfection and warming. This will reduce duration of the technological process, improve working conditions and increase labor productivity.

8. Conclusions

1. Wool must be warmed up and disinfected at the step of its primary processing before classification and sorting. One gram of wool can contain up to 700 million bacteria including the bacteria, which can cause death of human beings.

2. Theoretical studies have shown that the following parameters (frequency, power, exposure time) of EMF in the EHF range have to be used for suppression of pathogenic microorganisms in baled wool: 36 GHz, 0.5 kW, 3 min.

3. Increase in wool relative strength by 2.0–3.0 cN/tex and the breaking load by 200–300 cN is associated with the use of EMR with the established parameters.

References

1. Parton, K. Practical wool dyeing [Text] / K. Parton // Wool. – 2002. – P. 237–257. doi: 10.1533/9781855737648.237
2. Grove, C. C. The Influence of Temperature on the Scouring of Raw Wool [Text] / C. C. Grove // Amer. Dyestuff Rep. – 2008. – P. 13–16.
3. Simson, W. S. Wool chemistry [Text] / W. S. Simson // Wool. – 2002. – P. 130–159. doi: 10.1533/9781855737648.130
4. Hearle, J. W. Physical properties of wool [Text] / J. W. Hearle // Wool. – 2002. – P. 80–129. doi: 10.1533/9781855737648.80
5. Denning, R. Enhancing wool product using nanotechnology [Text] / R. Denning // Advanced in Wool Technology. – 2009. – P. 248–264. doi: 10.1533/9781845695460.2.248
6. Roche, J. The production of wool [Text] / J. Roche // The International Wool Trade. – 1995. – P. 17–38. doi: 10.1016/b978-1-85573-191-2.50005-9
7. Cotlee, D. J. World sheep and wool production [Text] / D. J. Cotlee // International Sheep and Wool Handbook. – 2013. – P. 1–48. doi: 10.7313/upo9781907284595.003
8. Wang, H. E. The Wool Shrink-Proof Technology of Sericin Bonding Wool [Text] / H. E. Wang // Advanced Materials Research. – 2013. – Vol. 690-693. – P. 1310–1313. doi: 10.4028/www.scientific.net/amr.690-693.1310
9. Potapkiy, P. V. The definition of the electromagnetic fields scattered by microorganisms in wool [Text] / P. V. Potapkiy, I. A. Sasi-mova, N. G. Kosulina // Bulletin of Kharkov national Polytechnic University. – 2010. – Issue 16. – P. 103–107.
10. Plonsi, R. Bioelectricity: a Quantitative approach [Text] / R. Plonsi, R. Barr. – Moscow: Mir, 1991. – 366 p.
11. Cerenkov, A. D. Impact low-energy electromagnetic measurements on the membrane potential and volume of cells of biological objects [Text] / A. D. Cerenkov // Microwave technology in the national economy. Introduction. Problems. Prospects. – Kyiv: TES, 2000. – P. 152–158.