TRIAL USING OF ULTRASONIC CAVITATION IN COTTONIZATION PROCESSES OF HEMP FIBERS

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Hych, O., Zakora, O., Rastorhuieva, M., Zilinskyi, A. (2021). Trial using of ultrasonic cavitation in cottonization processes of hemp fibers. ScienceRise, 4, 24–31. doi: http://doi.org/10.21303/2313-8416.2021.002042

ARTICLE INFO

Article history:
Received date 08.07.2021
Accepted date 19.08.2021
Published date 31.08.2021

Section:
Light industry

DOI

10.21303/2313-8416.2021.002042

KEYWORDS

textile materials
hemp fiber
physical and mechanical cottonization
ultrasonic cavitation

ABSTRACT

The object of research: ultrasonic processing technology of textile materials.

Investigated problem: increasing the degree of splitting of complex hemp fibers due to the effect of the mechanism of ultrasonic cavitation on them.

The main scientific results: The article shows the potential of textile production to ensure the environmental friendliness of textile products, and the development and implementation of new eco-technologies of physical and mechanical cottonization of hemp fiber is important in this. Analysis of existing methods of cottonization and structural features of hemp fibers has led to the conclusion that the destruction of cellulose satellites in complex fiber can be considered as a process of purification from impurities, since the technologies for purification of substances in the aquatic environment by ultrasound now are widely used. Therefore the process of cottonization of hemp by technology of ultrasonic treatment was used in this investigation for the first time. The basic principle effect on the textile material what placed in the liquid are the hydroacoustic effects formed by the collapse of cavitation bubbles in the contact zone "liquid-material". Experimental studies of the geometric characteristics of the obtained hemp cottonine were carried out, and the effectiveness of the effect of ultrasonic vibrations on the change of the structure of hemp fiber was confirmed. Due to the removal of inlaid substances under the action of cavitation, the complex fibers of hemp were split, as a result of which the range of variation and the absolute value of their length and linear density were decreased.

The scope of practical use of the research results: textile enterprises of deep processing of bast raw materials into technical and household yarns.

Innovation technological product: technology of ultrasonic cottonization of hemp fibers.

The scope of using the innovation technological product: manufacturing of textile hemp products for general use.

1. Introduction

1. 1. The object of research

The object of research is the technology of ultrasonic treatment of textile materials, which was first used for the cottonization of hemp fibers in order to reduce their length and thickness by splitting the fiber complexes and removing inlays. The phenomenon of ultrasonic cavitation which is realized with the help of specially developed ultrasonic cavitation equipment acts as a destructive mechanism.

1. 2. Problem description

With the rapid growth of the planet's population and the development of technology, environmental problems are becoming increasingly important, since it is mostly caused by textile production, which cannot do without the use of chemical technologies and emissions into the air and water bodies of harmful substances [1]. At the same time, the availability of consumer goods, which include textiles, is one of the main criteria, along with water quality and climate, which determine the state of the ecological situation in the region, i.e. quality of life. As a result, the modern textile market has begun to focus on the greening of products and the turnover of eco-textiles. Eco-textiles have become not just a fashion trend in the field of fashion and technical textiles, it is a requirement of time and a progressive society that strives to live well in harmony with the environment [2].

The production of ecological textiles in modern technologies of its production combines two components: the use of eco-friendly raw materials and the development of innovative eco-technologies for its processing [3, 4]. In this sense, the potential of the Ukrainian textile industry is to implement the following areas: the assimilation as a textile raw material of more and more hemp fibers, which due to their unique properties have a wide range of applications and most fully meet the requirements of greening; development of technologies for deep processing of hemp into spinnability fiber to sate the market with hemp-containing consumer goods (including clothing) with high environmental properties.

Climatic conditions of Ukraine allow introducing high-quality agrotechnology of hemp in most of its territory. At the same time, the selection development of non-narcotic varieties of hemp contributes to the development of this sector of the economy, and domestic agricultural producers have achieved significant success in the primary processing of stems of hemp plants [5]. For further assimilation of hemp raw materials it is necessary to develop domestic technologies of deep processing of technical fibers of hemp, the main of which is the process of cottonization.

1. 3. Suggested solution to the problem

Analysis of different methods of cottonization of bast fibers, conducted in [6], showed that the most promising method of cottonization is a physic-mechanical method, which is a symbiosis of a mechanical method of destruction of cellulose satellites in hemp fiber while using the effects of physical phenomena on the fiber, for example, temperature, pressure, electropulse discharges, etc. The study of these methods of cottonization, which are now being actively developed and improved, has revealed the disadvantages associated with damage to the cellulose component of the fibers and the high energy consumption of the cottonization process [7]. Further study of the disadvantages of existing methods of cottonization of bast fibers and the structure of hemp fibers suggested that the destruction of cellulose satellites in the complex fiber can be considered as a process of purification from impurities. Therefore, the idea arose to use as a process of cottonization of hemp fibers technologies for purification of substances in the aquatic environment using ultrasound, which are currently widely used in food technology, in techniques for cleaning various surfaces, including textiles [8]. It should be noted that modern scientists note the growing role of physical factors influencing technological processes in industry, in particular the energy of ultrasonic vibrations [9], which best meet the requirements of greening production.

To date, there are examples of scientific developments for the application of ultrasound for various purposes in textile technology. Ultrasonic vibrations are used to improve some properties of textile materials, for example, to increase the strength of polyvinyl chloride fiber [10]. This paper also demonstrates the effect of ultrasonic radiation on improving the wetting properties and capillarity of tissues, as a result of which the authors concluded that as the technique of generating powerful ultrasound improves, it may be economically and environmentally feasible to use it in many processes or in stream.

In [11], the authors propose to use ultrasonic waves to simplify one-stage processes of bleaching cotton fabrics due to intensive cavitation processes. At the same time, a parallel effect is obtained in the form of elimination of pectin, wax-like and trash impurities, as well as a decrease in the chemicalization and energy consumption of the process, which confirms that ultrasound is promising in the development of cleaner technologies.

There are attempts to use ultrasonic treatment of flax and hemp fibers in an aqueous solution of sodium hydroxide, resulting in the removal of small fragments and non-cellulosic carbohydrates simultaneously changes the porous structure of both fibers [12]. However, alkaline mixing in combination with ultrasound has different effects on the porous structure of flax and hemp fibers, which, according to the authors, depends on the heterogeneous cell wall structure of different bast fibers and different hemicellulose composition in their structure. As a result, under the action of ultrasound in an alkaline environment, the diameter of only hemp fibers decreases, while the diameter of flax fibers remains unchanged.

In [13] is presented a new technology of ultrasonic exposure to textile material, which is used to clean contaminated elastic surfaces (namely fabrics) through the use of high-intensity ultrasonic vibrations. During cavitation cleaning, the effect on pollution, as well as microorganisms, is due to physical processes under the action of high-intensity ultrasound, which passes through the liquid in which the textile material is placed. As a result, there is the phenomenon of acoustic cavitation, the determining parameter of which is the energy expended on the nucleation and development of cavitation bubbles, the collapse of which in the contact zone "liquid-material" determines the efficiency of a technological process [14]. Shock waves and cumulative jets destroy contaminants; tear them from the tissue fibers, overcoming the forces of adhesion and cohesion. The oscillations of the bubbles and the spreading shock waves generate microflows in the process solution, which promotes the mixing of the solution at the molecular level. A large number of bubbles provide high erosion activity of the cavitation medium, activates the liquid due to the formation of free radicals during the collapse of the bubbles and intensifies the chemical processes in the liquid [13]. Therefore, a detailed analysis of the mechanism of destruction of solid contaminants of fibrous materials by this technology allowed to hypothesize the possibility and feasibility of using ultrasonic cavitation in the technologies of cottonization of hemp to obtain from them straight fiber.

Therefore, the aim of this work is to study the possibility of using the technology of ultrasonic cavitation in the processes of deep processing of hemp raw materials to obtain fibers of the required length and thickness, suitable for the manufacture of household yarn.

2. Materials and methods

2. 1. Materials

The subject of the study is technical hemp fibers of imported origin, which have previously undergone a process of primary mechanical processing (source fibers). Visual analysis revealed that the fibers in this mixture differ significantly in geometric characteristics. According to the results of experimental studies, it was determined that the length of the fibers varies from 9 to 250 mm, and the linear density from 4.5 to 9.3 tex [15], which does not allow to process it into yarn by carded cotton spinning system. Therefore, this fiber must be prepared for the spinning process by conducting cottonization.

2. 2. Methods

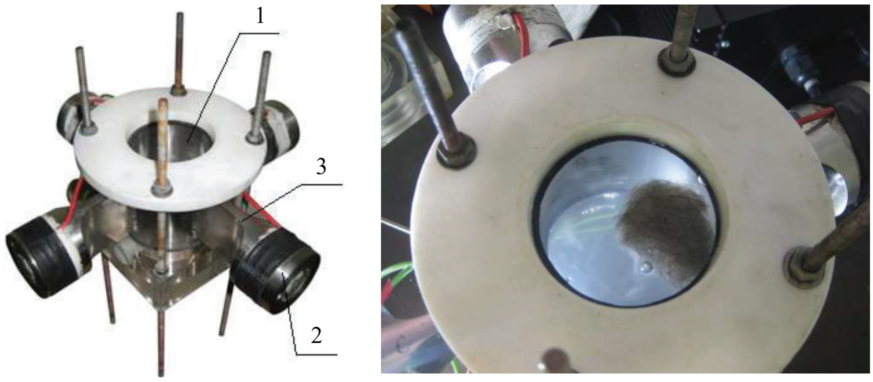
For the first time for the cottonization of hemp fiber used technological influence of ultrasonic cavitation, implemented using ultrasonic cavitation equipment developed by scientists of the National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute" and made according to the prototype given in [16], the basic principle of which is also presented in [17].

Fig. 1, *a* presents the main working part of the equipment, which is a tubular cylindrical cavitation chamber 1 (in the form of a glass), excited in the radial mode of oscillation by four piezoelectric ultrasonic drives 2 longitudinal movements, which are equipped with acoustic transformers 3 oscillating speed to the cavitation chamber from the outside. Focusing properties of the cylindrical surface of the radiation allow focusing ultrasonic oscillations along the axis of the cavitation chamber and achieving an oscillation intensity of more than 100 W/cm^2. In this case, on the cylindrical radiating surface, the intensity of oscillations is to be lower than it needs for the occurrence of ultrasonic cavitation, which would provide high efficiency of the introduction of ultrasonic oscillations into the cavitation chamber. The capacity of the cavitation chamber in the equipment is 270 ml. The water temperature in the cavitation chamber before the start of experimental studies was 18 °C. The test fiber was placed in the chamber. The power consumption of the ultrasonic emitter drives at which the research was conducted was 200 and 400 W, which was determined experimentally. The duration of cavitation in the study was 12 minutes during prolonged cavitation, the water in the cavitation chamber is heated, so when the water temperature reaches 70 °C, the water is changed to cold.

The study of the grade of change in the geometric characteristics (length and thickness) of hemp fibers before and after the application of the process of ultrasonic cavitation was carried out according to standard methods.

Sampling of hemp fiber for processing in ultrasonic cavitation equipment was carried out according to the method [18]. The results of the study of the grade of change in the geometric characteristics of fibers in the process of ultrasonic treatment are presented as the arithmetic mean of five samples selected for each stage of the experiment, determined taking into account the 95 % confidence level in experiments in the textile industry [19].

The length of the fibers was determined by the method of measuring single fibers according to the method presented in [20]. The thickness of the fibers is determined by the method of fiber splitting, followed by the calculation of their linear density [20, 21]. The choice of this method is justified by the fact that it allows to obtain a range of values of the linear density of hemp fibers and to analyse the nature of the unevenness of the fibers in thickness.



a *b*

Fig. 1. Ultrasonic cavitation equipment: *a* – appearance; *b* – placing a sample of hemp fibers in a cavitation chamber with water

3. Research results

Table 1 presents the results of determining the length of the original hemp fibers and the length of the fibers after ultrasonic treatment in two modes of cavitation.

According to **Table 1**, staple diagrams of the distribution of the length of hemp fibers and modal diagrams of length, this can be used to estimate the distribution of fibers by groups of lengths after each process of ultrasonic cavitation (**Fig. 2–4**).

To visualize the results and compare the degree of effect of ultrasonic treatment on the length of hemp fiber, modal diagrams on one coordinate plane is presented (**Fig. 5**).

Table 1

Distribution of hemp fibers by groups of lengths

Group of fibers in length	Fiber length, mm	Repetition rate (number of fibers in the group)					
		Source fiber		Cottonized fiber (200 W)		Cottonized fiber (400 W)	
		number	%	number	%	number	%
1	9	29	4.50	70	8.16	79	9.54
2	19	131	20.34	322	37.53	343	41.43
3	29	126	19.57	163	19.00	182	21.98
4	39	78	12.11	110	12.82	78	9.42
5	49	70	10.87	68	7.93	61	7.37
6	59	54	8.39	52	6.06	31	3.74
7	69	35	5.43	27	3.15	18	2.17
8	79	29	4.50	16	1.86	8	0.97
9	89	29	4.50	7	0.82	14	1.69
10	99	19	2.95	6	0.70	4	0.48
11	109	16	2.48	7	0.82	8	0.97
12	119	9	1.40	4	0.47	2	0.24
13	129	6	0.93	3	0.35	–	–
14	139	2	0.31	1	0.12	1	–
15	149	6	0.93	1	0.12	2	–
16	159	2	0.31	1	0.12	2	–
17	169	3	0.47	–	–	3	–
18	179	–	–	–	–	–	–
19	189	–	–	–	–	–	–
20	199	–	–	–	–	–	–
21	more 199	1	–	1	–	2	–
The total number of fibers		644	100.0	858	100.0	836	100.0

Note: data under the bold line are not calculated according to the method

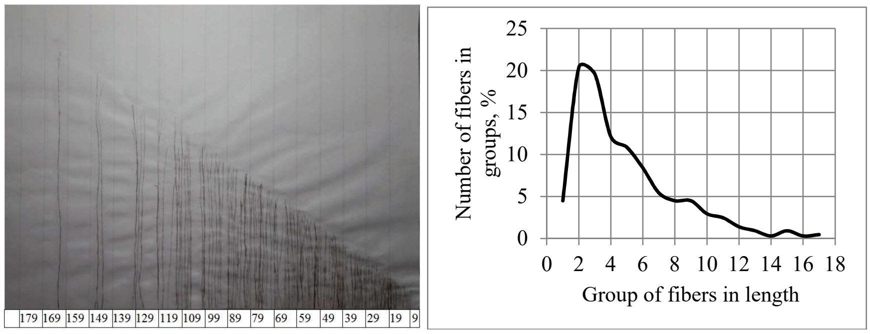


Fig. 2. Distribution of the length of the original hemp fibers (staple and modal charts)

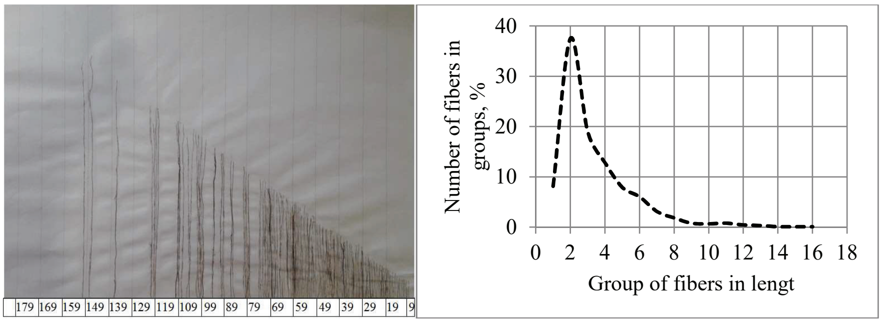


Fig. 3. Distribution of length of hemp fibers after ultrasonic processing with a power of 200 W (staple and modal diagrams)

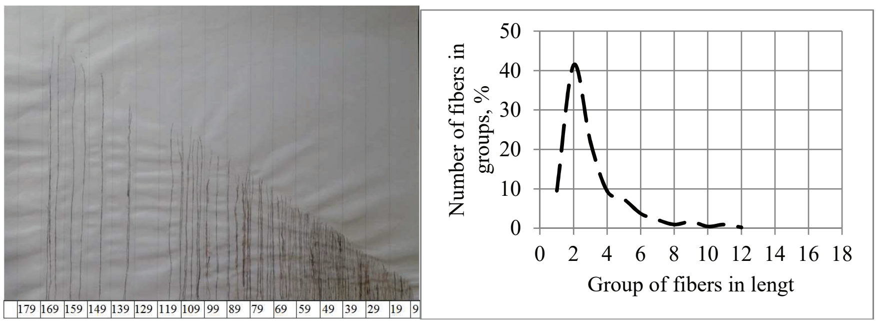


Fig. 4. Distribution of length of hemp fibers after ultrasonic processing with a power of 400 W (staple and modal diagrams)

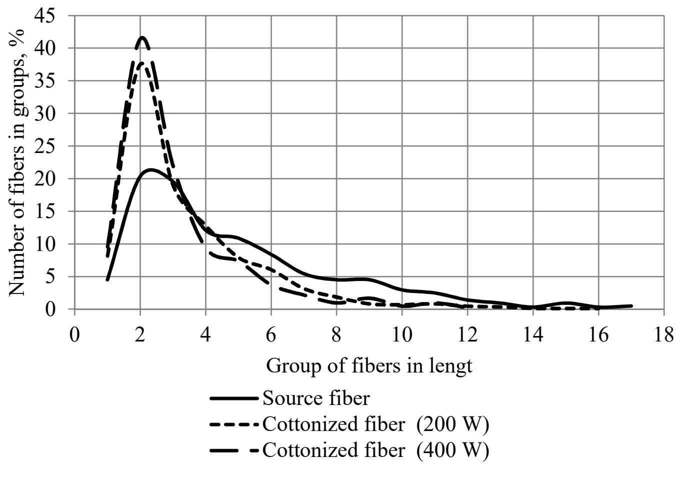


Fig. 5. Changing the length of hemp fibers in the ultrasonic process cavitation

4. Discussion

Analysis of modal diagrams presented in **Fig. 5**, proved that ultrasonic cavitation affects the length of hemp fibers, which is demonstrated by the significant difference in fiber lengths before and after the processing. The maximum length of the original fiber is 169 mm (see the staple diagram in **Fig. 2**), and the maximum length of the fibers after ultrasonic treatment is 159 and 119 mm, respectively. The total number of fibers of the spinneret group (length from 19 to 39 mm) in the raw material is 52.02 %, and after the processes of ultrasonic cavitation at a power of 200 and 400 W is 69.35 % and 72.83 % (**Table 1**). That is, there was an increase in the number of spun fibers by 17.33 % and 20.81 %, respectively. This leaves a small amount of long fibers (more than 100 mm long), which is 2 % and 1.21 %, respectively, which at this stage does not allow to process hemp cotton into yarn by carded spinning system. Therefore, the main direction of the study is to optimize and intensify the processes of ultrasonic treatment of hemp fiber to obtain the desired effect.

Visual examination of staple diagrams of the distribution of the length of hemp fibers suggested that their lumbar dimensions also decreased. To confirm these experimental studies of changes in fiber thickness under the action of ultrasonic cavitation were made. The results are presented in **Table 2**.

Table 2
Linear density of hemp fibers

Source fiber	Fiber obtained at a power of 200 watts	Fiber obtained at a power of 400 watts
4.5–9.3 tex	4.1–8.1 tex	3.6–7.2 tex

Analysis of the data presented in **Table 2**, confirms the effect of ultrasonic cavitation processes on the change in lumbar fiber size. This is not only a decrease in the absolute value of the linear density of the fibers, but also a decrease in the range of its variation.

The change in the lumbar dimensions of the fibers depending on the power of ultrasonic vibrations is demonstrated in microincisions of fibers (**Fig. 6**), which show that under the action of ultrasonic cavitation there is a decrease in the number of elementary hemp fibers in complexes.

a *b* *c*

Fig. 6. Microincisions of hemp fibers: *a* – source fibers; *b* – fibers obtained at a power of 200 watts; *c* – fibers obtained at a power of 400 watts

Thus, the application of the mechanism of acoustic cavitation, which is generated with the help of an ultrasonic cavitation apparatus, made it possible to reduce the geometric dimensions of hemp fibers due to the destruction of non-cellulosic substances (lignin and pectin) in hemp fibrous complexes under the action of the acoustic cavitation mechanism. That is, the processes of splitting complex hemp fibers took place similar to the processes of splitting when using, for example, electric discharge cavitation [7]. This caused a decrease in the diameter and length of the fibers. It should be noted that when processing complex hemp fibers with a certain amount of electrical impulse discharges [7], their linear density approaches the density of cotton fibers, but the length of the fibers that make up the spinning group rapidly decreases. That is, in comparison with the electric-discharge method, the acoustic cavitation mechanism does not have a gross destructive effect on the fiber, which is its advantage and a potential opportunity for optimizing the cottonization process. To date, there is no data on the use of the ultrasonic cavitation method for the cottonization of hemp fibers in order to obtain yarn from them using a carded spinning system. Successful results demonstrate work on the use of ultrasound for rapid processing of hemp straw. As a result, a fibril fiber is obtained and used as reinforcement for polymer thermoplastic composites [22]. Combined technologies of ultrasonic and chemical treatment are being introduced to change the surface structure of hemp raw materials [23]. Ultrasound is used to modify nanocellulose from hemp fibers in order to improve mechanical properties [24].

Thus, the scientific research presented in this article is the initial stage in the development of the technology for cottonization of bast fibers using ultrasonic hydrodynamic cavitation. At the moment, research is limited to laboratory conditions and a small volume of the cavitation chamber. A further direction of research is to determine the effect of the duration of the technological mode of ultrasonic cavitation on the degree of hemp fiber splitting.

6. Conclusion

1. The analysis of the scientific literature showed that the main requirement of modern textile production is its greening, the criteria of which can be met by the technology of deep processing of hemp into spinnable fiber by physical and mechanical cottonization.

2. For the first time for the implementation of physical and mechanical cottonization of hemp fibers used ultrasonic cavitation technology, the basic principle of which is the effect on the textile material placed in the liquid, hydroacoustic effects formed by the collapse of cavitation bubbles in the contact zone "liquid-material".

3. The effectiveness of ultrasonic cavitation on changing the geometric dimensions of hemp fiber has been experimentally proved. As a result of ultrasonic treatment of fibers at a power of 200 and 400 W, the length and thickness of the fibers decreased, which caused an increase in the number of spun fibers by 17.33 % and 20.81 %, respectively. This is not only a decrease in the absolute value of the length and linear density of the fibers, but also a decrease in the range of their variation. The presence of a small number of long fibers (more than 100 mm long) at this stage does not allow to process hemp cotton into yarn according to the carded spinning system and determines the direction of further scientific developments.

4. To determine the degree and range of intensity of the impact of ultrasonic cavitation on hemp fiber, depending on the technological parameters of the equipment, it is necessary to conduct additional experimental studies.

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