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Study on Electrophysical Properties in $KMnO_4$-Doped Grade "Xorazm-150" Cotton Fibers

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Original Research Article

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ABSTRACT

The main objective of the research was to identify the semiconducting characteristics of mature medium-thick (diameter 14, 15 µm) "Xorazm-150" cotton fibers both undoped and doped with 1.5% aqueous solution of $KMnO_4$, including current versus voltage and temperature dependence, temperature dependence of electrical conductivity, the influence of doping time on conductivity, and photoconductivity. The research was conducted in the temperature range (296-360 K) and the voltage range (0-100 V). The infrared spectra of the undoped and $KMnO_4$-doped samples were studied (Both samples were mercilized with NaOH). It was found that the cotton fibers sample doped with $KMnO_4$ had considerably higher electrical conductivity than the undoped sample. It was determined that the cotton fibers sample doped with $KMnO_4$ obeys the law of Ohm when current flows through it. Also, it was analyzed that the formation of photoconductivity of the cotton fibers

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sample doped with $KMnO_4$ under the influence of ultraviolet radiation indicates that the photoconductivity is mainly related to the formation of band electron-hole pairs. The deep surface created by doping cotton fibers with a 1.5% solution of $KMnO_4$ in water was found to have an activation energy that was determined from the results.

Keywords: Mercerization; cotton fiber; electrical conductivity; photoconductivity; current-voltage characteristics; diffusion.

1. INTRODUCTION

Many scientists are interested in understanding the electrical conductivity of polymers, especially natural fibers, the nature of charge transport in materials, and also researching their electrolytic properties [1-2]. Recently, the research of the physical and electrophysical properties of natural fibers is rapidly developing. Among other things, the discovery of the semiconductivity of cotton fibers (CF) is the basis for this [3-7].

According to the structure of CF, there are different layers and the composition of the structure of each layer has its own chemical composition [8]. The researches show that the electrophysical properties of cotton fibers are invisible in the cuticle part of the surface of the fiber. The cuticle layer has different characteristics in different varieties of CF. Therefore, expanding the scope of research allows to reveal of the general laws of electrophysical properties of CF and reveals the mechanisms of electrophysical processes occurring in fibers, as well as developing discrete elements of electronic devices (Smart Clothing Technology).

According to the analysis of the literature, various electrophysical properties of CF have been researched in the cited literature [4-6]. However, no research has yet been done on the electrophysical characteristics of grade CF "Xorazm-150". This article presents the electrophysical results of pure and $KMnO_4$-doped "Xorazm-150" CF treated with sodium hydroxide solution. The mobility and concentration of charge carriers best characterize the process of electrical conductivity. The electrical conductivity of natural fibers can be controlled in part by the doping process. The degree to which additives alter the resistance of polymers depends on their chemical makeup, how they interact with the macromolecular matrix, and the kind of physical flaws in natural fibers [3,5-7].

2. MATERIALS AND METHODS

First, the fibers from the ripe cotton seed were separated along 1 line with the parallel arrangement. In the initial state, 12000 to 15000 fibers per seed are combed through a special comb in one direction and reduced to 6000-8000 fibers. In the last sorting, the approximate number of parallel fibers was 4500-5000 pieces and the length was 4 mm, and the geometric mean of this sample was calculated. Before starting the doping process, cotton fibers tied in parallel are cleaned and mercerized. CF 75℃was washed in distilled water for 25 min. After washing, CF was kept in a bath with a solution of 20% NaOH in water at a temperature of 15℃for 2 min. After removing the CF from the bath, the excess NaOH, which did not form a chemical bond, is completely washed off with water and the samples are dried under standard conditions [9]. This process increases CF stability and input permeability. With this effect, CF increases diffusion efficiency. Mercerized CF was placed in a bath containing a 1.5% aqueous solution of $KMnO_4$ for 20 min. After the sample was taken from the bath, 3 samples were subjected to the doping process at a constant temperature of 80℃and for different times (1, 3, 6 hours). The purpose of doping each sample at different times is to study the dependence of electrical conductivity on doping time. Experiments show that the diffusion process takes place at 0-1-2-6 hours. At U = 100 V, the current passing through the sample increases from 0.15 nA to 35 nA (Fig. 1). This means that is mainly due to the diffusion of $KMnO_4$ into the layer on the surface of the cotton fiber (cuticle layer is about 0.5 µm) and the formation of additional charge carriers. The following special current-conducting liquid was prepared to create an ohmic contact between the CF samples and the metal conductor. A mixture of approximately 40% to 60% of graphite powder with liquid glass was obtained. The resistance of these Ohmic contacts is ≈100-200Ω•sm The volt-ampere characteristic (VAC) of the sample was measured under dark and ultraviolet UV light (wavelength 254 nm) using a Ш-300 electrometer at a small cur-rent level (in nano amperes). When taking measurements on a sample between ohmic contacts, the temperature was 298–360 K and the voltage was 1–100 V.

3. RESULTS AND DISCUSSION

The cellulose molecule is mainly in the cyclic state. When the cellulose molecule is analyzed using the infrared (IR) spectroscopy method, we can see the deformation vibration of the OH-group at 3324 cm^{-1}. It also falls in the area of 3281.5 cm^{-1}. When doped with $KMnO_4$, it has been observed that 3448.72 cm^{-1} OH is shifted in the molecule (Fig. 1).

It has been observed that the absorption maxima of the CH_2 group at 2898 cm^{-1} and 2858 cm^{-1} in the undoped Xorazm-150 grade cotton fibers sample are shifted to the area of 2955 cm^{-1} and 2855 cm^{-1}. It has been observed that the absorption lines corresponding to the C-O carbonyl group in the undoped molecule are shifted from 1631 cm^{-1} to 1634 cm^{-1}. It has been observed that the intensity has disappeared in the area of the fingerprint of the cellulose molecule and has passed into a semi-solid state Fig. 1 [10]. In conclusion, when Xorazm-150 grade cotton fibers are $KMnO_4$-doped, we can consider that $KMnO_4$ molecules are mainly located in the defects between cellulose molecules and are connected by Van-Der-Waals, valence, and electrostatic bonds.

The dependence of the current on the voltage (in the dark and under the light of 254 nm wavelength), and the influence of the doping time on the conductivity of the pure and $KMnO_4$-doped samples of ripened "Xorazm-150" cotton fibers were researched. When we apply voltage to an undoped sample, It has been seen that a very small amount of current has passed into the calculation of specific conductivity (Fig. 2, line 1). It has been observed that by diffusing the input into the sample, a much higher current flow is achieved compared to the initial conductivity (Fig. 2). It was observed that the volt-ampere characteristic VAC is linear in the direct and reverse current flow to the sample. Fig. 2 shows the VAC undoped sample (Fig. 2, line 1) and $KMnO_4$-doped sample at different times (Fig. 2, lines 2, 3, 4) in the constant temperature of 80℃. From the Figure below, it has been observed that by increasing the diffusion time in the order of 1, 3, and 6 hours, the permeability of the sample was observed to increase.

I-V characteristics were measured in the dark and under UV radiation under normal conditions. An OBN-60 (hν≈5,0 eV) lamp was used as a light source. In Fig. 3, it has been seen that the I-V characteristic in the dark (1) and under UV light (2) is linear. When we increased the voltage from 0 to 100 volts, it was observed that the result obtained under UV light differed by up to 19 nA compared to the result obtained in the dark. Under UV light (254 nm), the photocurrent (PC) increased to 54 nA at 100 V. Under UV light (254 nm), the photocurrent increased to 54 nA at 100 V. The formation of photoconductivity in CF can be explained by the doping of $KMnO_4$ into CF [11].

In order to better understand the mechanism of electrical conductivity of "Xorazm-150" grade CF doped with $KMnO_4$, the temperature dependence of electrical conductivity was researched. The laws of Ohm were used for the whole chain and part of the chain to measure the electrical conductivity (σ) of samples made of cotton fiber with semiconducting properties. The electrical conductivity of the sample at appropriate temperatures was determined by the following formula. $\sigma = \frac{4\,I\,l}{U\pi n d^2}$ where I – given voltage and the current flowing through the sample at a certain point of temperature in the appropriate case, U – the voltage applied to the sample (U=50 V was taken as a constant in the measurements), l – length of the sample in the direction of current flow, n – the average number of fibers in the sample, d – average diameter of one fiber. The research was carried out in the temperature range of 295-350 K on "Xorazm-150" grade CF doped-$KMnO_4$ at t=80℃for 7 hours. It has been observed that the electrical conductivity increases exponentially with increasing temperature (Fig. 4a). Analyzing the results, the following can be said: $KMnO_4$ "Xorazm-150" grade CF formed a deep layer. In the temperature range given above, one activation energy of the sample was determined. The amount of activation energy was determined by the Arrhenius plot (Fig. 4b).

In Fig. 4, we can observe that the current increases with the temperature increase at a voltage of 50V given to the sample. In this case, the temperature coefficient of electrical conductivity is positive, and this is a characteristic of the semiconductor material. Similar properties of CF have been observed by other scientific groups [12]. It was found that the activation energy of $KMnO_4$-doped "Xorazm-150" grade of CF is 0.54 eV through the temperature dependence of electrical conductivity.

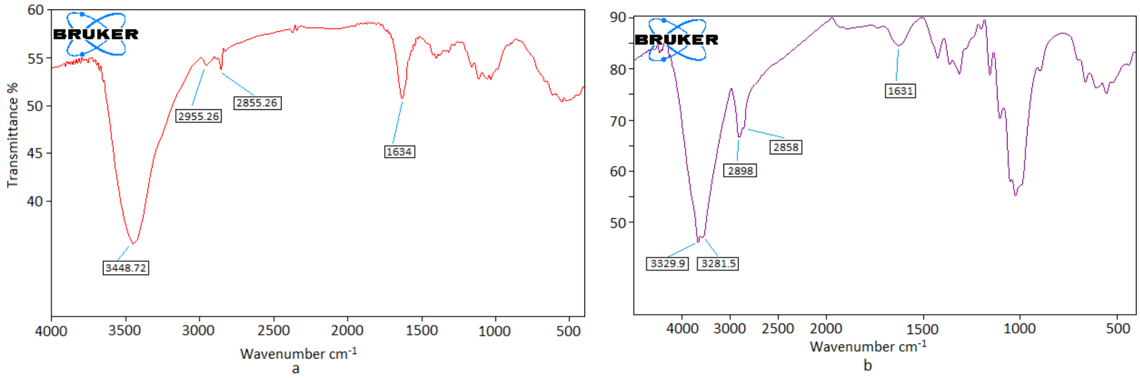

Fig. 1. IR spectrum of $KMnO_4$-doped (a) and undoped (b) cotton fibers of Xorazm-150 grade (Both samples were mercilized with NaOH before heat treatment)

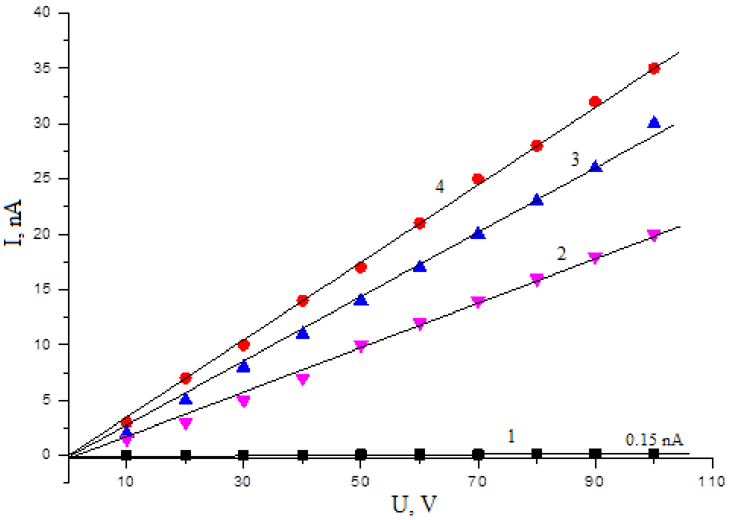

Fig. 2. The volt-ampere characteristics of samples of "Xorazm-150" cotton fibers were undoped (1) and doped with $KMnO_4$ at different times (2,3 and 4). t, hour: 2-1.0; 3-3.0; 4-6.0

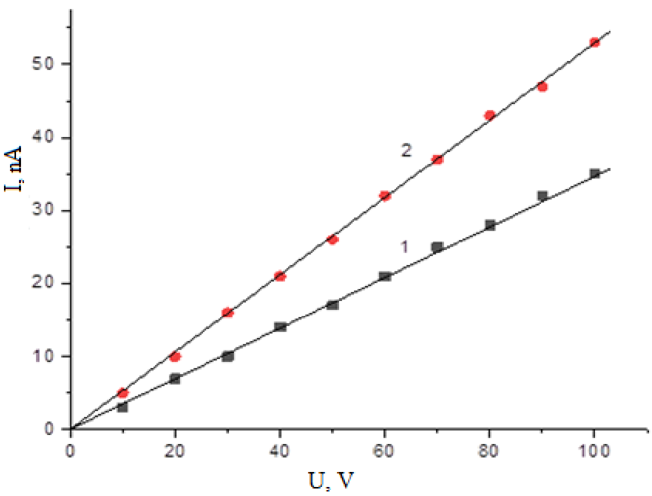

Fig. 3. Volt-ampere characteristics of the "Xorazm-150" grade CF sample mercerized and doped with $KMnO_4$ at t=80℃ for 7 hours in the dark (1) and under light of wavelength $\lambda \geq 254$ nm (2)

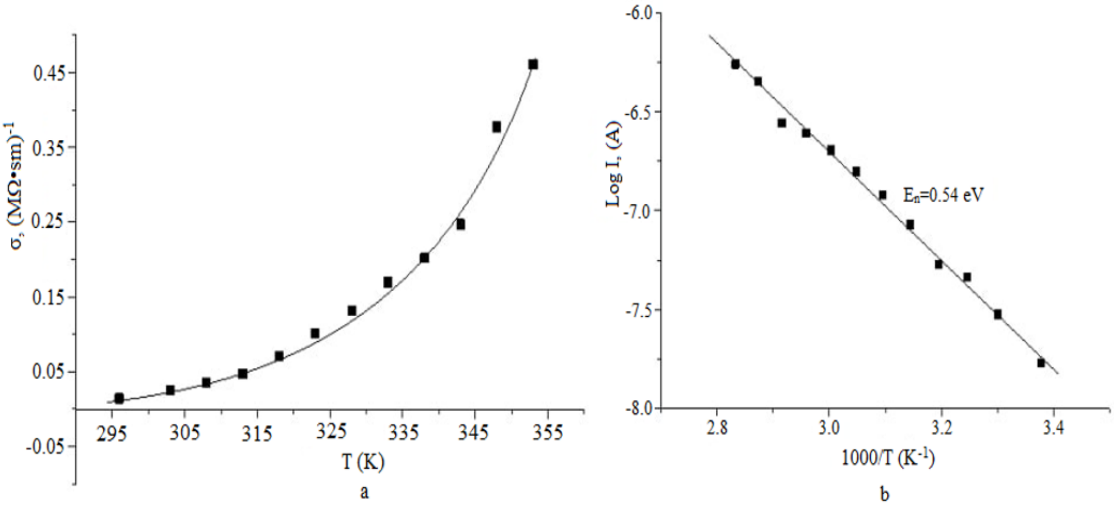

Fig. 4. Temperature dependence of electrical conductivityσ of a sample of "Xorazm-150" grade CF $KMnO_4$-doped at t=80℃ for 7 hours (a) and Arrhenius diagram of this result (b)

4. CONCLUSION

According to the conclusion, the electrophysical properties of undoped and $KMnO_4$-doped CF were studied. According to the analysis of the experimental results, it was found that the conductivity increased by several 10 times when "Xorazm-150" grade CF mercerized with NaOH was doped with $KMnO_4$, and the doping time depended on the conductivity.

A sharp increase in the conductivity of CF doped with $KMnO_4$ is associated with an increase in the concentration of charge carriers in CF. Input molecules are located in the lattice defects of the polymer and form a deep level in the forbidden zone, and as a result, free charge carriers are formed that ensure conductivity even at room temperature. We can control the concentration of charge carriers generated at room temperature by diffusing $KMnO_4$ into the cotton fibers at different times (T=const).

The conduction mechanism of undoped CF is mainly explained by the Poole-Frencel conduction mechanism. In addition, the formation of photoconductivity under the influence of UV radiation indicates that photoconductivity is mainly related to the formation of band electron-hole pairs and can be explained by the order of charge transfer between $KMnO_4$ molecules and polymer networks possible. Based on the obtained results, the activation energy of the deep surface produced by doping CF with $KMnO_4$ was determined.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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