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STUDY OF PHYSICOCHEMICAL PROPERTIES OF ADSORBENTS OBTAINED BASED ON TEXTILE CORD

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This paper examines the physicochemical principles and principles of textile cord recycling to produce adsorbents. The accumulation of used automobile tires and their use as secondary products, coupled with the lack of suitable recycling processes and technologies, has prompted the search for effective ways to recycle worn tires and use them as a promising raw material to produce carbon-containing materials. Textile cord, a byproduct of organic rubber waste recycling, was selected as a substandard raw material to produce carbon-containing materials. The structure formation processes of composites modified with textile wire have been described inconsistently in terms of the mechanism of formation, volume, type, size, and differential porosity. Therefore, this paper presents a comprehensive study of the influence of additives on the properties and structure of composites with the goal of producing porous carbon adsorbents for water and gas purification from textile cord from waste automobile tires.

Keywords: automobile tire waste, activation, organic waste, porous adsorbents, nanomaterials, carbonization.

ТОҚЫМА СЫМЫ НЕГІЗІНДЕ АЛЫНҒАН АДСОРБЕНТТЕРДІҢ ФИЗИКА-ХИМИЯЛЫҚ ҚАСИЕТТЕРІН ЗЕРТТЕУ

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Жұмыста адсорбенттер алу үшін тоқыма сымдарын қайта өңдеудің физика-химиялық принциптері мен принциптері қарастырылады. Пайдаланылған автомобиль шиналарының жинақталуы және оларды қайталама өнім ретінде пайдалану, сәйкес қайта өңдеу процестері мен технологияларының жоқтығы тозған шиналарды қайта өңдеудің тиімді жолдарын іздеуге және оларды көміртегі бар материалдарды өндіру үшін перспективалық шикізат ретінде пайдалануға түрткі болды. Құрамында көміртегі бар материалдарды өндіру үшін сапасыз шикізат ретінде органикалық резеңке қалдықтарын қайта өңдеудің жанама өнімі болып табылатын тоқыма шнуры таңдалды. Тоқыма сымымен модификацияланған композиттердің құрылымды қалыптастыру процестері түзілу механизмі, көлемі, түрі, өлшемі және дифференциалды кеуектілігі тұрғысынан сәйкес келмейтін сипатталған. Сондықтан бұл жұмыста автомобиль шиналарының қалдықтарынан тоқыма шнурларынан су мен газды тазарту үшін кеуекті көміртекті адсорбенттерді алу мақсатымен композиттердің қасиеттері мен құрылымына қоспалардың әсерін кешенді зерттеу ұсынылады.

Түйін сөздер: автомобиль шиналарының қалдықтары, активация, органикалық қалдықтар, кеуекті адсорбенттер, наноматериалдар, карбонизация.

ИЗУЧЕНИЕ ФИЗИКО-ХИМИЧЕСКИХ СВОЙСТВ АДСОРБЕНТОВ, ПОЛУЧЕННЫХ НА ОСНОВЕ ТЕКСТИЛЬНОГО КОРДА

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В работе рассмотрены физико-химические основы и закономерности способа переработки текстильного корда с целью получения адсорбентов. Проблема накопления использованных автомобильных шин и применение их в качестве вторичной продукции, отсутствие подходящих процессов и технологий переработки явилось основой поиска эффективных способов переработки изношенных шин, применение их в качестве перспективного сырья для производства углеродсодержащих материалов. В качестве некондиционного сырья для производства углеродсодержащих материалов выбран продукт переработки органических отходов резины – текстильный корд. Процессы формирования структуры композитов, модифицированных текстильной проволокой неоднозначно описаны по механизму возникновения новообразований, объему, типу, размерам и дифференциальной пористости. В связи с этим, в работе проведены комплексные исследования влияния добавок на свойства и структуру композитов с целью получения пористых углеродных адсорбентов для очистки воды и газов из текстильного корда отходов автомобильных покрышек.

Ключевые слова: отходы автомобильных шин, активация, текстильный корд, пористые адсорбенты, наноматериалы, карбонизация.

Introduction. Today, one of the fastest-growing industries globally is tire manufacturing. The global tire market reached 2,268 million units in 2021 and is projected to reach 2,665 million units by 2027. According to the European Tire and Rubber Manufacturers Association, the number of end-of-life tires amounted to 3.56 million tons in 2019, which is approximately 1% less than the previous year [1-3]. Overall, 65% of rubber products are used in automotive applications, and the recycling and reuse of partially worn tires in the domestic market remain at a very low level [4,5].

Porous carbon-based materials are obtained through thermal treatment or activation using various oxidizing agents. These materials act as sorbents, enabling the efficient separation of gas and liquid mixtures, while their sorption properties enhance separation capabilities. Such carbon materials are widely used as sorbents, catalyst carriers, nanocomposite materials, and substrates in next-generation energy storage devices such as lithium-ion batteries, supercapacitors, ionistors, and fuel cells [6-9].

Currently, the development of carbon adsorbents derived from automotive tire waste is rapidly advancing. This direction helps address waste recycling challenges while producing efficient materials.

For example, in studies on Turkic peoples, textile cord was processed using the pyrolysis method, followed by chemical activation with potassium hydroxide (KOH). It was found that these materials effectively remove organic pollutants, particularly methylene blue, from aqueous solutions. The best results were observed at a pH of 6.5, highlighting the importance of controlling acidity in adsorption processes [10]. Additionally, other researchers have investigated the role of pyrolysis temperature and duration. It was shown that increasing the temperature improves pore structure and increases the specific surface area, which is a crucial factor for gas storage or water purification applications [11].

Our activation method for textile cord stands out from other approaches, as it provides a high carbon content (86.53%) along with enrichment in mineral elements (Si, Ca, Fe, V, P) that create additional active sites. Moreover, the liquid product is rich in aromatic compounds (toluene, ethylbenzene, etc.), giving it added value. Unlike many studies focused only on surface area, our approach combines high activation efficiency with the practical significance of both solid and liquid products.

Materials and methods. The following equipment was used to carry out this research: a laboratory quartz reactor, a BR-12NRT rotary tube furnace, a ”Thermostep Eltra”

thermogravimetric analyzer, a Kristallux-4000M gas chromatograph, an ES-20/60 shaker-incubator, a PD-303 spectrophotometer, a 150-MI pH meter, a C-2204 centrifuge, a ”GRAD” ultrasonic bath, and a Quanta 3D 200i EDAX scanning electron microscope.

To obtain carbon adsorbents, the activation process was carried out in a laboratory setting at a temperature of 800°C in an inert atmosphere (nitrogen gas). The physicochemical properties were analyzed using a thermogravimetric analyzer, while the adsorption properties were determined in the presence of methyl orange. The technological process was conducted in two stages: carbonization (at 700°C) to remove highly volatile components and achieve a uniformly distributed large-pore structure, followed by activation (at 900°C) to develop a microporous structure. The experiments were performed in a laboratory-scale steam-gas activation unit.

The methods for determining the properties included moisture content, ash content, volatility, pH value of the aqueous extract, bulk density, adsorption activity with methyl orange, pore volume in water, elemental composition, and specific surface area (BET method).

Textile cord consists of several primary materials, each influencing its mechanical properties and strength. The main component is polyester, accounting for 50–70% of the composition, providing tensile strength. Polyamide (nylon) constitutes 10–20%, enhancing mechanical properties and wear resistance. Steel wires make up 10–15%, adding extra hardness and durability.

Results and discussion. The technological process was carried out in two stages: carbonization (to remove volatile components and produce a large-porous structure uniformly distributed throughout the volume) and activation (to produce a microporous structure). Experiments were conducted on a laboratory steam-gas activation unit (Fig.1).

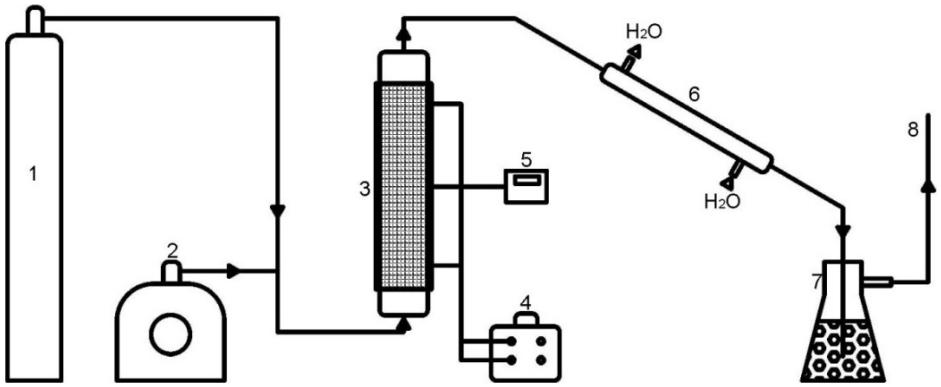


Fig.1 - Schematic diagram of a laboratory setup for steam-gas activation:
1 - gas cylinder (nitrogen), 2 - steam generator, 3 – reactor, 4 – LATR, 5 - temperature sensor, 6 - direct condenser, 7 - flask for cleaning gas from resins, 8 - gas outlet

Carbonization was carried out in an inert argon atmosphere at temperatures ranging from 400 to 900°C for 60 minutes. Argon was supplied from a cylinder (1) to the reactor at a set flow rate of 20 ml/min, which was adjusted using a flow meter. After leaving the reactor, the gas was directed to a condenser (6), from which a portion of the condensed gas flowed into a flask (7) to remove resinous substances. Unreacted gases were discharged to the ventilation system (8).

The next step in adsorbent preparation was activation with water vapor (flow rate of 10 ml/min) at the maximum temperature for 60 minutes to improve its adsorption properties. Table 1 shows the temperature dependences of the components of the gas obtained as a result of carbonization and activation of nylon cord. The formation of combustible gas components (CO, H_2, CH_4) occurs

according to the following main chemical reactions:

$$2H_2O \rightarrow 2H_2 + O_2 - 115700 \text{ kcal} \quad (1)$$

$$C + H_2O \rightarrow CO + H_2 - 28150 \text{ kcal} \quad (2)$$

$$C + CO_2 \rightarrow 2CO - 38400 \text{ kcal} \quad (3)$$

$$C + 2H_2 \rightarrow CH_4 + 18600 \text{ kcal} \quad (4)$$

When heated above 200 , textile cord begins to decompose, forming a flammable gas containing hydrogen, carbon monoxide, alkanes and alkenes.

Table 1 - Gas composition of carbonization and activation of textile cord

Process	T1 C°	Gas composition (volume, %)								
		O_2	H_2	CO_2	N_2	CH_4	CO	C_2H_6	C_2H_4	C_3H_8+ C_3H_6
Carbonization	200	37.003	0.046	0.126	32.911	0.166	0.040	0.005	-	0.589
	300	37.874	0.259	1.139	68.089	0.083	-	0.009	0.335	0.020
	400	43.355	0.237	2.219	66.944	0.045	-	0.036	0.680	0.054
	500	34.788	3.380	1.874	58.749	1.082	-	1.095	0.705	1.012
	600	34.526	3.091	1.671	61.023	2.570	-	0.918	0.565	1.012
Activation	700	30.469	3.873	0.411	76.123	0.746	-	0.137	0.036	0.162
	800	28.204	5.608	0.302	75.943	0.813	0.436	0.066	0.080	0.082
	900	27.532	3.304	0.157	79.477	0.841	0.511	0.038	0.058	0.006

Table 2 - Material Balance of Textile Cord after activation

	Name	Massa, g	Amount, %
Initial Material	Textile cord	200.00	66.67
	Water	100.00	33.33
	Total	300.00	100.00
Product	Solid Residue (adsorbent)	68.40	22.80
	Gas	201.66	67.22
	Liquid product (water+tar)	29.94	9.98
	Total	300.00	100.00

The analysis of gaseous products shows that during carbonization an increase in temperature leads to higher hydrogen release (up to 3.091% at 600 °C) and formation of light hydrocarbons (CH_4, C_2–C_3), while oxygen decreases. At the same time, nitrogen remains the dominant component of the mixture. During activation (700-900 °C), the gas phase is characterized by high nitrogen content (over 75%) along with noticeable hydrogen formation (up to 5.608% at 800 °C) and small amounts of CO and hydrocarbons. These results indicate that thermal treatment

intensifies decomposition processes and promotes gas evolution, enriching the system with hydrogen and light hydrocarbons.

As a model system, automotive tire waste was crushed and sieved to separate the rubber granules and textile cord. The obtained textile cord underwent carbonization and activation by being processed in a pyrolysis furnace at 900°C for 4 hours. The material balance was then calculated (Table 2).

The developed system boasts a simple and reliable design, as well as an environmentally friendly technology. The gas phase and solid residue are used as adsorbents for water and gas purification, and various commercial products can be obtained from the liquid fraction, which is a mixture of hydrocarbons. No wastewater is generated during operation.

During the carbonization and activation of the textile cord, the vapor-gas mixture was diverted to a refrigerator, where the hydrocarbon vapors condensed, forming a resin. The liquid products obtained in this process at temperatures ranging from 400 to 900°C were distilled on a rotary evaporator (at temperatures of T = 55-61°C under vacuum), with the hydrocarbon fractions collected. Figure 2 shows the chromatograms of the liquid products obtained from the carbonization and activation of the textile cord.

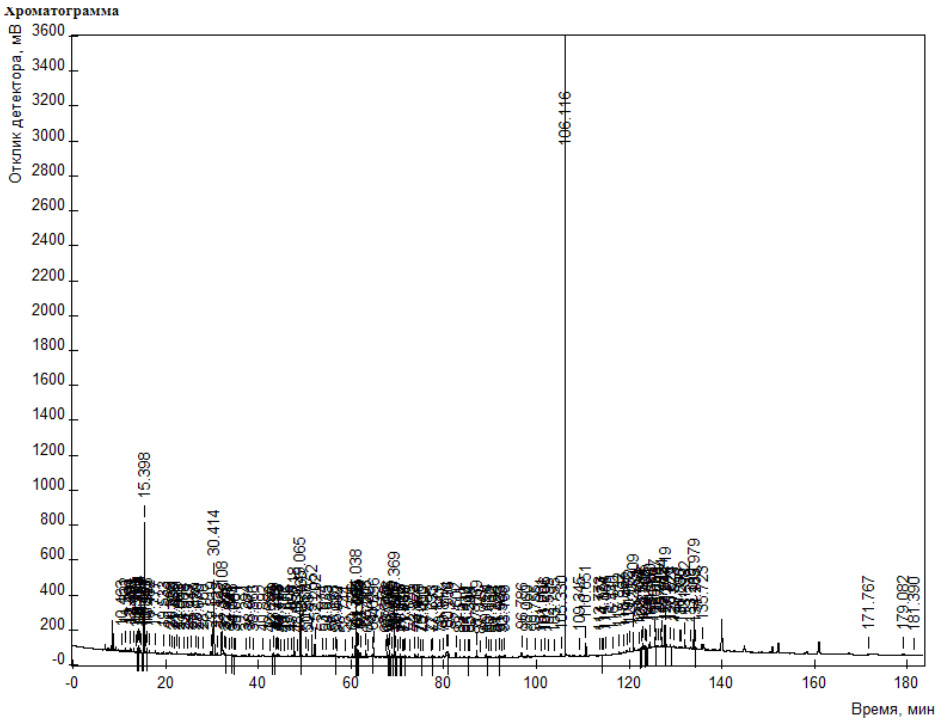


Fig.2 - Chromatogram of liquid products from carbonization and activation of nylon cord

According to the analysis results, the component composition of the liquid hydrocarbon fractions formed during the carbonization and activation of the textile cord is predominantly toluene with a retention time of 30.414 min and a concentration of 10.525%, indicating its dominant content in the mixture. The second most abundant component is 2-methyl-3-ethylpentane (3.329%, retention time 32.108 min). Aromatic hydrocarbons were detected in smaller quantities: ethylbenzene (2.093%, 47.718 min) and 1-methyl-3-n-butylbenzene (1.018%, 80.714 min), as well as other compounds in trace amounts. The obtained results indicate the predominance of aromatic compounds, among which toluene is the main representative, which can have a significant impact on the physicochemical properties of the studied sample.

The elemental composition of the initial product and the adsorbent based on textile cord were studied using a portable X-ray fluorescence analyzer (Table 3).

Table 3 - Elemental composition obtained using a portable X-ray fluorescence instrument

Elemental composition	Initial textile cord		Activated textile cord	
	%	±2σ	%	±2σ
C	77.89	0.57	86.53	0.36
Zn	4.74	0.14	-	-
S	5.30	0.15	6.01	0.15
Si	0.636	0.040	1.95	0.07
Cl	0.260	0.010	0.311	0.010
K	0.310	0.20	0.476	0.020
Ca	0.721	0.031	1.74	0.06
Fe	0.603	0.028	3.06	0.08
Ti	0.153	0.067	0.183	0.064
V	-	-	0.054	0.033
P	-	-	0.055	0.031

The elemental composition analysis of the original and activated textile cord revealed significant changes after activation. The carbon content increased from 77.89% to 86.53%, indicating enrichment of the carbon matrix due to the removal of volatile compounds and inorganic impurities. Sulfur slightly increased (5.30% to 6.01%), while zinc, initially present at 4.74%, completely disappeared, suggesting volatilization during thermal treatment. At the same time, mineral components became more concentrated: silicon rose from 0.636% to 1.95%, calcium from 0.721% to 1.74%, and iron from 0.603% to 3.06%, with minor increases in chlorine, potassium, and titanium. Notably, vanadium (0.054%) and phosphorus (0.055%) appeared only in the activated material, likely due to redistribution of trace elements or impurities introduced during activation. Overall, the activation process not only enriched the carbon structure but also significantly transformed the mineral profile of the textile cord, which may strongly influence its adsorption and catalytic properties.

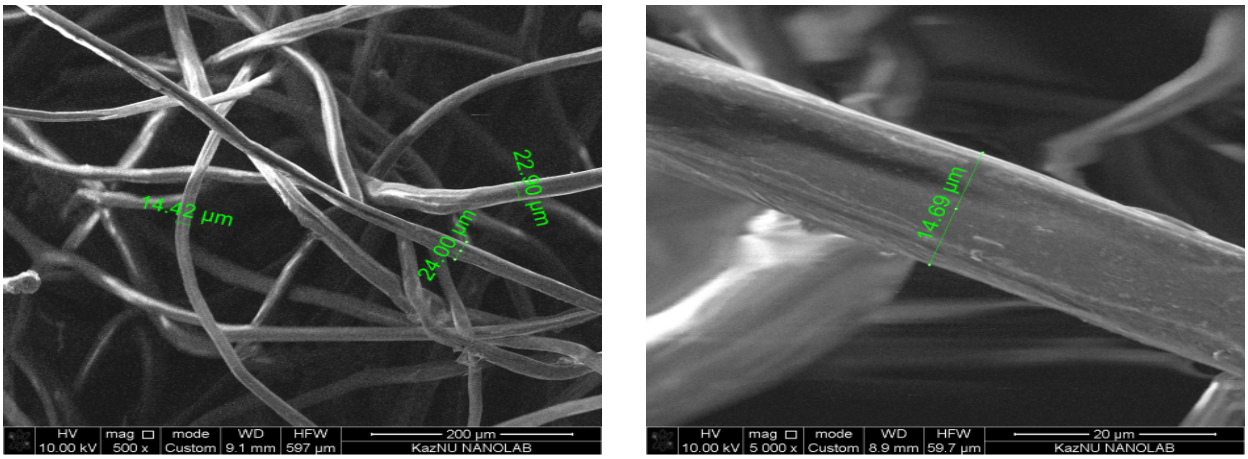
Figures 3 and 4 present microscopic images of the initial textile cord and the activated adsorbent, respectively.

In Figure 3, fiber particles with a diameter of 10–25 μm are clearly visible, with structural elements forming fibrils in the form of thread-like formations.

As shown in Figure 4, the analysis of micrographs reveals that after thermal treatment, the surface structure changes, particle sizes decrease (~145 nm), and fine-dispersed carbon nanoparticles with diameters ranging from approximately 70 to 600 nm are formed. This may be associated with the interaction of reactive radicals resulting from carbonization and activation, leading to the formation of new compounds. The most likely cause of nanoparticle formation on the surface is the synthesis process from the gas phase.

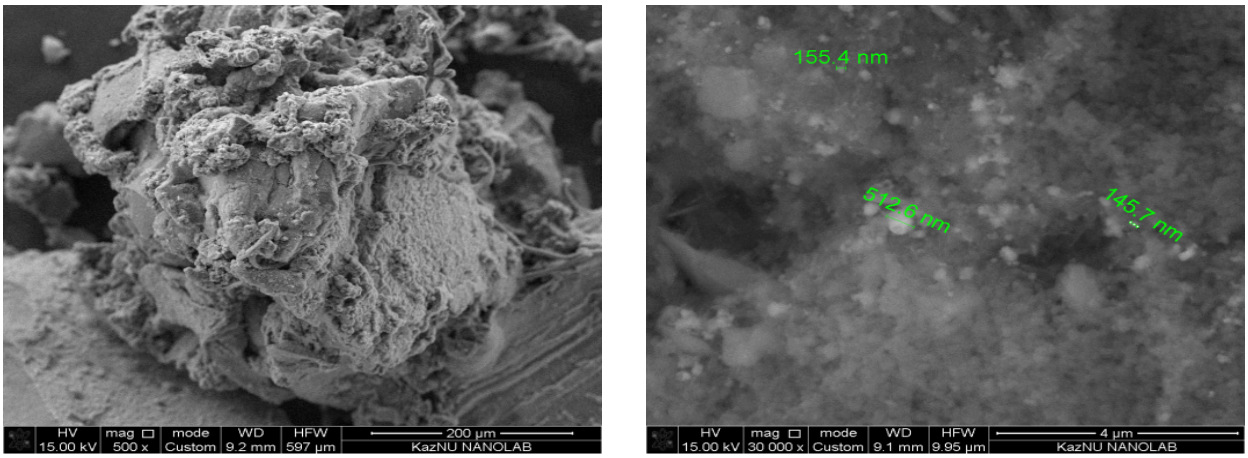
During thermal treatment, the formation and growth of ordered carbon in the textile cord may occur through the self-organization of carbon nanoparticles without the involvement of a

mesophase. However, further studies are needed to clarify this issue.



a **b**

Fig.3 - SEM results of the Initial Textile Cord: a-x500; b-x5000



a **b**

Fig.4 - SEM results of the Activated Textile Cord: a-x500; b-x5000

Thus, the method of processing textile cords through carbonization and activation in the recycling of automobile tires not only ensures the disposal of worn-out tires but also enables the production of materials that can be used in various industries.

Conclusion. Traditional methods for purifying natural objects are not always effective and may harm the environment. While using organic waste for wastewater and air purification is economically and environmentally beneficial, such materials generally lack the required sorption capacity, necessitating carbonization and activation. As a result of this process, new sorbents are obtained, combining the beneficial properties of the original material with the characteristics of synthetic sorbents, and having a surface different from the initial mineral.

Thus, the proposed method for processing textile cords derived from automobile tire recycling through carbonization and activation not only facilitates the disposal of worn-out tires but also enables the production of materials that can be used in various sectors of the economy.

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