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OBTAINING POROUS CARBON MATERIAL AND INVESTIGATION OF ITS PHYSICAL AND CHEMICAL PROPERTIES

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The work carried out a physicochemical analysis of porous carbon material (PCM) obtained from brown coal from the Maikuben basin (Kazakhstan). PUM was obtained by carbonization and activation in argon and water vapor. The electrophysical characteristics of the PCM were determined by measuring the electrical capacitance of the samples in the temperature range 293–483 K. The resulting product exhibits high characteristics, including high dielectric permittivity, specific surface area, and capacity, making it effective for use in supercapacitors as an electrode material and for hydrogen storage. The coal carbonization process includes an initial low-temperature (at 180°C, with a heating rate of 10°C/min) treatment of the raw material in the presence of air for 1 hour, followed by carbonization in an inert atmosphere at temperatures ranging from 180-900°C with a heating rate of 5°C/min, and steam activation at the maximum temperature for 1 hour of the coal ground to a 0.1 mm fraction. The material is then extruded into cylindrical shapes (diameter: 2-3 mm, length: 5-10 mm) using a binder material: starch - 5%, sodium hydroxide - 0.5%, water - 17% of the total mass of coal.

Keywords: porous carbon material (PCM), brown coal, carbonization, activation, thermal decomposition, activated carbon.

КЕУЕКТІ-КӨМІРТЕКТІ МАТЕРИАЛДЫ АЛУ ЖӘНЕ ОНЫҢ ФИЗИКАЛЫҚ-ХИМИЯЛЫҚ ҚАСИЕТТЕРІН ЗЕРТТЕУ

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Жұмыс барысында Майкөбен бассейнінің (Қазақстан) қоңыр көмірінен алынған кеуекті көміртекті материалға (ККМ) физика-химиялық талдау жүргізілді. ККМ аргон мен су буында карбонизация және активтену арқылы алынды. ККМ электрофизикалық сипаттамалары 293–483 К температура диапазонында үлгілердің электр сыйымдылығын өлшеу арқылы анықталды. Алынған өнімнің жоғары сипаттамалары бар, оның ішінде жоғары диэлектрлік өтімділігі, меншікті бетінің ауданы және сыйымдылығы бар, бұл оны суперконденсаторларда электрод материалы ретінде пайдалану үшін, сондай-ақ сутегі сақтау үшін тиімді етеді. Көмірді карбонизациялау процесі шикізатты 1 сағат бойы ауа қатысында төмен температурада (180°С, қыздыру жылдамдығы 10°С/мин), содан кейін температура диапазонында инертті ортада көміртектеуді қамтиды. 180-900°С қыздыру жылдамдығы 5°С/мин және су буымен 1 сағат максималды температурада белсендіріледі, көмірдің 0,1 мм фракциясына дейін ұсақталады, содан кейін цилиндрлік пішіндерге экструдталған (диаметрі 2-3 мм, ұзындығы 5-10 мм) байланыстырушы материалды пайдалана отырып: крахмал – 5%, натрий гидроксиді – 0,5%, су – 17% көмірдің жалпы массасынан.

Түйін сөздер: кеуекті көміртекті материал (ПКМ), қоңыр көмір, көміртендіру, активтену, термиялық ыдырау, белсендірілген көмір.

ПОЛУЧЕНИЕ ПОРИСТО-УГЛЕРОДНОГО МАТЕРИАЛА И ИССЛЕДОВАНИЕ ЕГО ФИЗИКО-ХИМИЧЕСКИХ СВОЙСТВ

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В работе проведен физико-химический анализ пористо-углеродного материала (ПУМ) полученного на основе бурого угля Майкубенского бассейна (Казахстан). ПУМ получен методом карбонизации и активации в средах аргона и водяного пара. Определены электрофизические характеристики ПУМ путем измерения электроемкости образцов в интервале температур 293–483 К. Полученный продукт имеет высокие характеристики, включая высокую диэлектрическую проницаемость, удельную поверхность и емкость, что делает его эффективным для использования в суперконденсаторах в качестве электродного материала, также для хранения водорода. Процесс карбонизации угля, включал предварительную низкотемпературную (при 180°С, со скоростью нагрева 10°С/мин) обработку сырья в присутствии воздуха в течение 1 часа, затем карбонизацию в инертной среде в интервале температур 180-900°С со скоростью нагрева 5°С/мин и активацией водяным паром при максимальной температуре в течение 1 часа измельченной до фракции 0,1 мм угля, а затем экструдированием в цилиндрические формы (диаметр-2-3 мм, длина 5-10 мм) с применением связующего материала: крахмал - 5 %, гидроксид натрия – 0,5 %, вода – 17 % от общей массы угля.

Ключевые слова: пористо-углеродный материал (ПУМ), бурый уголь, карбонизация, активация, термическое разложение, активированный уголь.

Introduction. Porous carbon nanomaterials, such as biochar, graphene, and carbon nanotubes, have a wide range of applications in heavy metal adsorption, energy storage, and sensor technologies due to their excellent properties, such as high specific surface area (SSA) and high electrical conductivity. Various synthesis methods for porous carbon materials have been developed using a broad spectrum of raw materials. For instance, chemical vapor deposition (CVD) is employed to produce high-quality graphene from methane. However, these methods are complex, and the raw materials used are either rare or expensive, hindering the large-scale production and commercialization of advanced carbon materials [1-5].

Biomass is an exciting raw material for advanced porous carbon nanomaterials through simple pyrolysis. Typically, the production of porous carbon nanomaterials from biomass has two main advantages. First, the cost of producing porous carbon nanomaterials can be significantly lower. Biomass has diverse sources, ranging from straw, husks, leaves, peels, to microorganisms and chitin, which are low-cost products of agriculture, industry, and daily life. Second, it helps mitigate environmental pollution caused by biomass. Biomass is usually discarded, leading to environmental pollution, especially a large amount of carbon dioxide (CO_2) released into the atmosphere, exacerbating the greenhouse effect. To address the issue of electromagnetic radiation pollution, a simple method exists for producing porous carbon using coal processing residues as a carbon source [6-14].

The intensification of environmental issues, the need for comprehensive wastewater treatment, gas emissions purification, and the disposal of hazardous components necessitate the development of new methods and approaches for creating industrial adsorbents [15]. This also involves a more rational approach to the use of natural resources, the application of hydrocarbon recovery processes, or the concentration of rare metals from highly diluted solutions. One optimal solution to these challenges may be the comprehensive use of high-quality and cost-effective carbon adsorbents, such as activated carbons [16]. Due to their physicochemical properties, carbon adsorbents are unique and ideal sorption materials that can address a wide range of issues related to ensuring chemical, biological, and radiation safety for humans, the environment, and infrastructure. Among all available adsorbents, activated carbons are the most versatile, capable of absorbing a wide spectrum of toxicants [17-18].

There are several methods for producing porous carbon material and studying its physicochemical properties. One of the most common methods is the thermal decomposition of organic substances (pyrolysis) in the absence of oxygen (or at very low concentrations) followed by an activation process, which involves treating the carbon structures with chemical reagents or steam at high temperatures. This increases the material's porosity, forming micro-, meso-, and macropores.

The obtained porous carbon material is subjected to various analytical methods to study its physicochemical properties. This can include measuring the porous structure (specific surface area, specific pore volume, pore size distribution, sorption capacity, etc.), surface chemical analysis (spectroscopy, chromatography), electrochemical property studies, and other methods [19].

Porous carbon materials can be applied in a wide range of fields, including supercapacitors, catalysts, water purification, hydrogen storage, and other areas [20]. Porous carbon materials (PCM) with a high specific surface area (up to 1200 m^2/g), open slit-type porosity, high electrical conductivity, chemical stability, and low specific weight have the potential to significantly improve the specific characteristics of energy storage devices. PCMs based on coal can be utilized in micro- and nanoelectronics, particularly as solid-state electrode materials for supercapacitors, and can be used as energy storage devices and power supplies for various high-power consumers that have strict requirements for environmental friendliness, cyclic resource, and readiness for operation, such as in electric vehicles, solar panels, and satellites. These materials can store much more energy than traditional capacitive elements, doing so for extended periods without charge leakage [21].

Materials and Methods. There are numerous methods for producing porous carbon materials from various carbon-containing substances. The main difference between these methods is the aggressive reaction environment required for the carbonization process, which necessitates costs for washing and neutralizing the pH, as well as energy expenditures for drying the products.

The proposed method involves the following stages: thermal treatment of the raw material in an inert gas atmosphere up to 900ºC, followed by activation of the carbon material.

The main advantages of this method are the use of readily available raw materials, specifically brown coal from Kazakhstan (Maikuben basin, Shoptykol deposit, $W\_^{daf}$ – 12.11%, $A\_^{daf}$ – 23.44%, and $V\_^{daf}$ – 40.66%); the use of steam instead of caustic sodium for activation; the production of a ready-to-use product through extrusion; and the production of PCM with high dielectric permittivity ($\varepsilon = 1.12 \times 10^9$ at 483 K), a specific surface area of 348.99 m^2/g, specific resistance of 3-4 ohms, and a capacitance of 1.2-1.7 μF.

The electrophysical properties (dielectric permittivity and electrical resistance) of the obtained samples were measured using an LCR-800 series device (Taiwan) at a working frequency of 1 kHz in dry air under a thermostat regime with a fixed temperature hold time. The Sawyer-Tower circuit was used to obtain the relationship between electric induction (D) and electric field strength (E). Visual observation of the D(E) hysteresis loops was conducted on an S1-83 oscilloscope with a voltage divider consisting of 6 MΩ and 700 kΩ resistors and a reference capacitor of 0.15 μF. The generator frequency was 300 Hz. For all temperature studies, the samples were placed in a furnace, and the temperature was measured using a chromel-alumel thermocouple connected to a V2-34 voltmeter with an error of ±0.1 mV. The temperature change rate was approximately 5 K/min. The dielectric permittivity at each temperature was determined using the formula $\varepsilon = C/C_0$, where C_0 is the capacitance of the capacitor without the test substance (air).

The specific resistance and capacitance of the PCM were measured using a digital multimeter "UT-70 B" (China).

The chemical analysis and surface morphology of the PCM were studied using energy-dispersive X-ray spectroscopy (EDS) on a SEM (Quanta 3D 200i) equipped with an EDAX EDS attachment. The excitation electron beam energy was 15 keV.

The phase composition of the PCM was identified using X-ray diffraction. The X-ray phase analysis was conducted on a DRON-2 setup. Shooting conditions: FeKα radiation, U = 28 kV, J = 28 mA.

The adsorption characteristics of the PCM (specific surface area) were studied using the Brunauer-Emmett-Teller (BET) method. Measurements were conducted on a KATAKON Sorbtometer M device.

Carbonization and Activation

Carbonization and activation were carried out in a laboratory high-temperature rotary furnace BR-12NRT (Figure 1).

Fig. 1-High-Temperature Rotary Tube Furnace BR-12NRT

The coal underwent an initial low-temperature treatment (at 180°C, with a heating rate of 10°C/min) in the presence of air for 1 hour, followed by carbonization in an inert atmosphere at temperatures ranging from 180-900°C with a heating rate of 5°C/min, and steam activation at the maximum temperature for 1 hour. The coal was ground to a 0.1 mm fraction, extruded into cylindrical shapes (diameter: 2-3 mm, length: 5-10 mm) using a binder material: starch - 5%, sodium hydroxide - 0.5%, water - 17% of the total mass of coal.

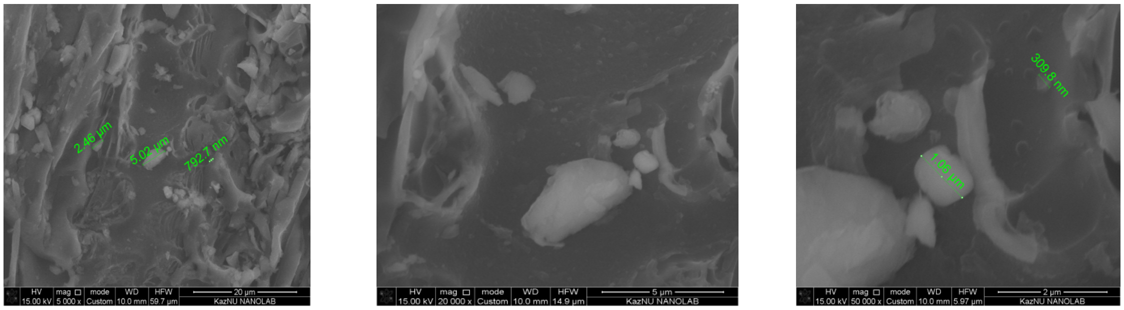
Results and Discussion. The results of the elemental analysis of the PCM obtained at 900°C, presented in Table 2, indicate that after the thermal treatment of the coal, a significant portion of the volatile components are removed as gaseous products, thereby increasing the concentration of the mineral constituents.

Table 1-Chemical Composition of PCM

Element	**C**	**O**	**Mg**	**Al**	**Si**	**K**	**Ca**	**Fe**
Raw Coal, wt%	62.33	24.88	0.34	3.39	6.71	0.73	0.37	0.87
PCM, wt%	60.69	19.44	0.58	5.29	10.09	01.05	0.75	1.60

The X-ray phase analysis showed that the PCM is almost X-ray amorphous, with weak reflections of SiO_2, Fe_2O_3, and K_2O observed.

Micrographs of the raw coal samples and the activated PCMs derived from it are shown in Figure 2.



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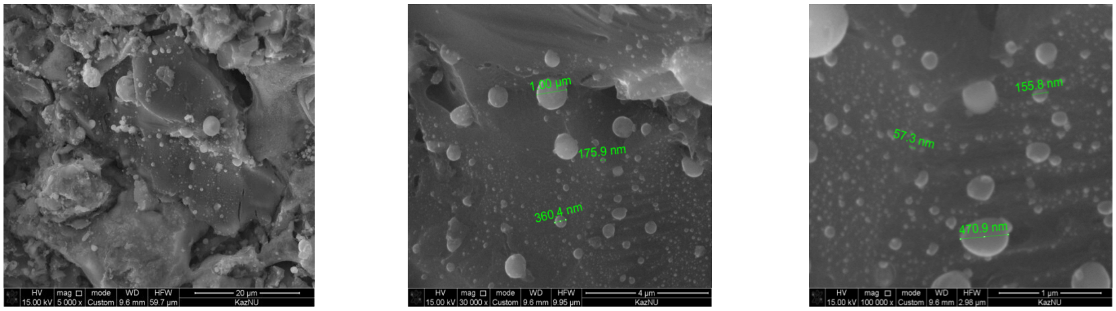
(a) (b) (c)



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(d) (f) (g)

Fig. 2 - Scanning Electron Microscope Images of Raw Coal (a) – (c) and PCM (d) – (g)

The analysis of the surface morphology of raw coal revealed a heterogeneous structure characterized by flake-like inclusions in the carbon matrix and particles with a plate-stepped shape. The SEM images show that after thermal activation of the coal, the surface structure becomes more developed with smaller particle sizes. The specific surface area and specific pore volume significantly increase compared to the raw sample-from 5.11 to 348.99 m^2/g, approximately 70 times greater due to high-temperature activation. The SEM images of the PCM show the formation of fine nano- and macro-particles of silicon on the surface, with diameters ranging from ~50 nm to ~1 μm.

The results of electrophysical studies show that PCM obtained at 300°C exhibits metallic conductivity in the range of 293-373 K, semiconductor conductivity at 373-413 K, metallic again at 413-443 K, and semiconductor conductivity at 443-483 K. The bandgap width at 373-413 K is 1.68 eV, and at 443-483 K, it is 2.24 eV, classifying the PCM as a narrow-band semiconductor. The dielectric permittivity values are low, with the specific surface area of the adsorbent being 7.51 m^2/g. The specific resistance of PCM is higher than MΩ, and the PCM does not exhibit capacitance accumulation.

PCM obtained at 400°C shows metallic conductivity in the range of 293-333 K, semiconductor conductivity at 333-383 K, metallic again at 383-433 K, and semiconductor conductivity at 433-483 K. The bandgap width at 333-383 K is 1.24 eV, and at 433-483 K, it is 1.84 eV, classifying it as a narrow-band semiconductor. The dielectric permittivity values are also low, with the specific surface area of the adsorbent being 20.95 m^2/g. The specific resistance of PCM is higher than MΩ, and the PCM does not exhibit capacitance accumulation.

PCM obtained at 500°C shows semiconductor conductivity in the range of 293-353 K, metallic conductivity at 353-403 K, semiconductor again at 403-473 K, and metallic conductivity at 473-483 K. The bandgap width at 293-353 K is 0.79 eV, and at 403-473 K, it is 1.24 eV, classifying it as a narrow-band semiconductor. The dielectric permittivity values are low, with the specific surface area of the adsorbent being 161.42 m^2/g. The specific resistance of PCM is higher than MΩ, and the PCM does not exhibit capacitance accumulation.

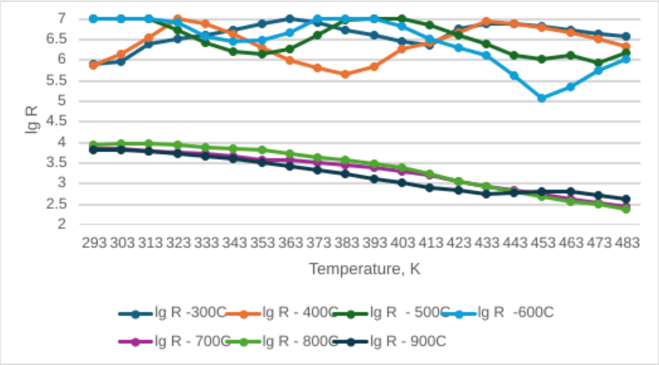
PCM obtained at 600°C shows semiconductor conductivity in the range of 293-343 K, metallic conductivity at 343-393 K, semiconductor again at 393-463 K, and metallic conductivity at 463-483 K. The bandgap width at 293-343 K is 0.87 eV, and at 393-463 K, it is 1.37 eV, classifying it as a narrow-band semiconductor. The dielectric permittivity values are low, with the specific surface area of the adsorbent being 150.98 m^2/g. The specific resistance of PCM is higher than MΩ, and the PCM does not exhibit capacitance accumulation.

PCM obtained at 700°C exhibits semiconductor conductivity in the range of 293-353 K, metallic conductivity at 353-363 K, and semiconductor conductivity again at 363-483 K. The bandgap width of this adsorbent in the range of 293-353 K is 0.75 eV, and at 363-483 K, $\Delta E = 0.86$ eV, classifying it as a narrow-band semiconductor. This adsorbent also possesses giant dielectric permittivity values: $1.87 \cdot 10^7$ at 293 K and $1.01 \cdot 10^9$ at 463 K, making this material highly promising for microcapacitor technology. The specific surface area of the adsorbent is 156.26 m^2/g. The specific resistance of PCM is 280-600 Ω. The capacitance of PCM is 0.01 μF.

PCM synthesized at 800°C shows metallic conductivity in the range of 293-313 K and semiconductor conductivity in the range of 313-483 K. The bandgap width in the range of 313-483 K is 0.59 eV, classifying it as a narrow-band semiconductor, with high dielectric permittivity values increasing from $1.56 \cdot 10^7$ (at 293 K) to $6.48 \cdot 10^8$ (at 453 K). This adsorbent is also of interest for microcapacitor technology. The specific surface area of the adsorbent is 241.945 m^2/g. The specific resistance of PCM is 250-270 Ω. The capacitance of PCM is 0.58 μF.

PCM obtained at a higher temperature of 900°C exhibits semiconductor properties in the range of 293-433 K, and metallic properties at 433-453 K. A second-order phase transition is observed at 433 K. This material has significantly high dielectric permittivity values: ~33 million at 293 K and over one billion ($1.12 \cdot 10^9$) at 483 K. The PCM sample is of interest both as a semiconductor and as a promising material for microcapacitor technology. The specific surface area of the adsorbent is 348.99 m^2/g. The specific resistance of PCM is 3-4 Ω. The capacitance of PCM is 1.2-1.7 μF.

At high temperatures ranging from 700°C to 900°C, an increase in dielectric permittivity (ε) is observed (Figure 3). The data shows that PCM obtained at 900°C exhibits giant dielectric permittivity values, reaching up to $1.12 \cdot 10^9$ at 483 K, making it a highly promising material for microcapacitor technology. The increase in dielectric permittivity can be explained by the increase in the specific surface area of PCM, as the specific capacitance of electrode materials is directly proportional to the specific surface area. The increase in specific surface area is due to the carbonization of the raw material in the temperature range of 700-900°C, where heteroatoms are removed, and the structure of flat aromatic rings develops, forming basic structural units or elementary graphite crystallites.



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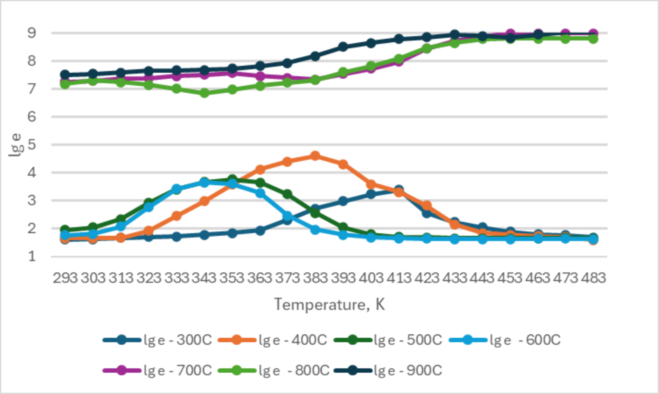

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Fig. 3 - Dependence of Electrical Resistance (R) and Dielectric Permittivity (ε) on Temperature for PCM Obtained at Different Temperature Intervals

Part of the carbon transitions from sp^3 to sp^2 state, while some is removed with gaseous and liquid components. Graphenes, consisting of flat polycyclic aromatic molecules with two-dimensional ordering of carbon atoms, form in the solid material volume. Steam activation creates microporous structures by opening pores that are in a closed state in the carbon material. Based on the analysis of the diagrams constructed from the experimental data, the following conclusions can be drawn:

Dielectric Permittivity (ε): an increase in the processing temperature of coal leads to a significant increase in the dielectric permittivity of the material; the highest level of dielectric permittivity is achieved at 900 ºC, indicating the potential of the material for microcapacitor technology. The ε value reaches 33 million at 293 K and exceeds 1 billion at 483 K.

Logarithm of Dielectric Permittivity (lg ε): the logarithm of dielectric permittivity also shows a positive correlation with the processing temperature, confirming the trend of increasing ε with higher temperatures.

Logarithm of Specific Resistance (lg R): the logarithm of specific resistance demonstrates an inverse relationship with temperature. As the processing temperature increases, the specific resistance decreases, making the material more conductive; materials processed at higher temperatures (700-900 ºC) show the lowest specific resistance values, indicating improved conductive properties.

Comparison of Different Processing Temperatures. Increasing the coal processing temperature from 300 ºC to 900 ºC results in significant changes in its electrical properties. Materials processed at higher temperatures exhibit better dielectric permittivity and specific resistance characteristics.The most pronounced changes are observed in the temperature range of 700-900 ºC, where there is a sharp increase in ε and a decrease in R.

Overall, the conducted studies show that increasing the coal processing temperature to high values significantly improves its electrical properties, making the porous carbon material promising for use as semiconductor and electrode materials in various electrochemical applications.

To explain the observed changes in types of conductivity in porous carbon material (PCM) at various temperatures, several factors should be considered: phase transitions, structural changes in the material, and alterations in the band structure of the material.

Phase Transitions. As the temperature changes, PCM can undergo several phase transitions that affect its electronic properties. For example, transitions between metallic and semiconducting states may be due to changes in the crystalline structure of carbon, such as transitions from sp^2 hybridization (characteristic of graphite) to sp^3 hybridization (characteristic of diamond) and vice versa.

Structural Changes. When heated to high temperatures (700-900°C), PCM undergoes the removal of volatile components and restructuring of the carbon matrix, leading to an increase in specific surface area and changes in the porous structure. These changes can significantly affect the material's electronic conductivity.

At temperatures of 400-500°C. An alternation of metallic and semiconducting conductivity is observed. This can be explained by the fact that at these temperatures, the carbon structure of the material is in an intermediate state where different regions can exhibit different types of conductivity. Metallic regions may be associated with graphene-like structures, while semiconducting regions are related to amorphous carbon. Example: at 400°C, the material first exhibits metallic conductivity and then semiconducting conductivity, which is related to the restructuring of the carbon matrix with increasing temperature.

At temperatures of 500-600°C. The opposite sequence is observed: first semiconducting, then metallic conductivity. This may be due to further changes in the material's structure, where larger graphene regions begin to dominate, altering the overall nature of the conductivity. Example: at 500°C, the material first exhibits semiconducting conductivity and then metallic conductivity, which may indicate a phase transition occurring at this temperature.

At temperatures of 700°C. Only three changes are observed: semiconducting, metallic, semiconducting. This indicates stabilization of the structure, where part of the material has already transitioned into a stable state with semiconducting properties. Example: at 700°C, the disappearance of the fourth change may be related to the material reaching a certain degree of crystallinity, where further phase transitions become less pronounced [22].

At temperatures of 800°C. Changes are observed again, but only twice: first metallic, then semiconducting conductivity. This indicates a further simplification of the material's structure, where large graphene regions dominate. Example: at 800°C, the material exhibits metallic conductivity, indicating a significant predominance of graphene-like structures, followed by a transition to a semiconducting phase with further heating.

At temperatures of 900°C. The material changes conductivity again, but only twice: semiconducting and metallic. This may indicate the material reaching a state close to a fully ordered graphene structure with small areas of amorphous carbon. Example: at 900°C, the material exhibits semiconducting conductivity, followed by metallic conductivity, indicating the achievement of a certain degree of crystallinity.

These observations suggest that the structural changes and phase transitions within PCM at varying temperatures significantly influence its electrical properties. The alternation between metallic and semiconducting conductivities is a result of the complex interplay between the material's microstructure and its electronic states, which are temperature-dependent [23].

The aforementioned findings are supported by scientific works. For example, in the scientific article [24], the influence of temperature on the structure and properties of porous carbon materials, including changes in conductivity, is investigated. In [25], structural changes in nanoporous carbon materials at high temperatures and their impact on electrical conductivity are studied. Reference [26] discusses the role of graphitization in altering the electronic properties of carbon materials, which is relevant to the observed changes in conductivity. Finally, [27] examines the effects of activation on the conductivity and structure of graphene-based materials.

Conclusions. Thus, the correlation between conductivity and the properties of porous carbon materials (PCM) can be observed.

Electrical Conductivity. The change in conductivity indicates a complex internal structure of PCM, where regions with different electronic properties coexist. These variations impact the overall electrical conductivity of the material, which is crucial for its applications in electronics and energy sectors.

Dielectric Permittivity. High dielectric permittivity of PCM, especially at elevated temperatures, indicates the material's capability to store electrical energy, making it promising for use in supercapacitors.

Specific Surface Area. An increase in specific surface area with higher activation temperatures enhances the adsorption properties of the material, which is beneficial for applications in filters and catalysts.

These dependencies and properties of PCM demonstrate that controlling the thermal treatment conditions allows for the targeted modification of its physicochemical properties for optimal use in various technological processes.

In a carbonized product, crystallites are located in fits and starts, the spaces between them are filled (or blocked) with amorphous carbon, which is formed during the separation of resinous substances. When activated by water vapor, a chemical reaction occurs on the surface of the pores between water vapor and carbon. As a result of the process, a very developed pore structure is formed and the internal surface of the coal increases, as indicated by the results of the study, where the specific surface area and specific pore volume increase significantly compared to the untreated sample from 5.11 to 348.99 m^2/g, which is approximately 70 times more due to high temperature activation. SEM images of PUM show the formation of small nano- and macroparticles of silicon with a diameter from ~ 50 nm to ~ 1 μm on the surface, which also affects the electrical properties of the samples. Based on the research findings of the porous carbonaceous material (CM), several key characteristics have been investigated for its potential applications as semiconductor and electrode materials: specific resistance, energy capacity, as well as electrical resistance and dielectric permeability. It is noteworthy that increasing the temperature from 300°C to 900°C results in an increase in dielectric permeability (ε) and a decrease in electrical resistance (R) of the carbonaceous material. Consequently, the CM material shows promising characteristics for electrode materials: at 293 K, it exhibits an ε value of 33 million, surpassing the benchmark $BaTiO_3$ by 25,000 times, and at 483 K ($\varepsilon > 1$ billion), exceeding $BaTiO_3$ by 463,000 times.

Moreover, it should be highlighted that the dielectric permeability of this relatively inexpensive carbonaceous material can compete with the similar characteristic of the new La15/8Sr1/8NiO4, which demonstrates a gigantic dielectric permeability value of 105-106. These findings demonstrate the prospects for using this product in the electrochemical industry.

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