ANNOTATION

for the dissertation degree of Doctor of Philosophy (PhD)
according to the educational program
"8D07113- "Nanomaterials and nanotechnology in chemistry"
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"Development of technology and research of a filter-sorption nanostructured system for purifying water from microplastics and organic pollutants"

General characteristics of the work: This dissertation is aimed at investigating the possibility of using environmentally friendly cold plasma technology to decompose and eliminate new sources of water pollution - microplastics and organic pollutants. In addition, the use of activated carbon as adsorbents to improve water purification efficiency and achieve high levels of purification is assessed.

Relevance of the work: Currently, the negative impact of microplastics and persistent organic pollutants (POPs) on the environment is one of the global environmental problems. The global scientific community is actively studying the distribution of microplastics in aquatic ecosystems and its impact on living organisms and ecosystem processes. The UN Environment Report for 2021 notes that 9-14 million tons of plastic waste enter the oceans every year, and this figure could triple by 2040. Microplastics - particles no more than 5 mm in diameter - do not decompose in the natural environment and are widely distributed through water resources, raising concerns about their impact on the environment and human health.

Recent studies have shown that microplastics can enter the human body through water, air and food, causing long-term toxic effects. According to scientists, each person consumes an average of 5 grams of microplastics per week, which is about the weight of a credit card. These data demonstrate the scale of microplastics in the food chain and their potential health risks.

The methods currently used (coagulation, flotation, adsorption, photocatalysis, biodegradation) often require large energy costs or lead to the formation of indirect waste. In this regard, the development of effective, environmentally friendly systems combining plasma-chemical methods and adsorption technologies is a pressing task.

Cold plasma (CP) technology has been recognized as a promising method in water purification processes in recent years. This method allows for the complete mineralization of organic pollutants in water, forming highly reactive compounds such as radicals and ozone.

The need to solve water purification problems worldwide:

- According to the World Health Organization (WHO), 30% of the world's population does not have access to clean drinking water.
- Water quality decline in developing countries is accelerating due to industrial and agricultural pollution, according to a 2022 UNESCO report.
- The European Chemicals Agency (ECHA) noted in 2021 that microplastics and their derivatives persist in the environment for hundreds of years and that their complete elimination is necessary.

Thus, the improvement of water purification technologies and the use of modern methods will contribute to ensuring global environmental safety. The aim of this study is to effectively purify water from microplastics and persistent organic pollutants by proposing an innovative method combining cold plasma and activated carbon.

The aim of the work: development and research of an effective nanostructured filter-sorption water purification system for the degradation of microplastics and the removal of persistent organic compounds. This system aims to create an environmentally safe and highly efficient water purification technology by combining the use of cold plasma and activated carbon for the adsorption of degradation products.

Objectives of the dissertation:

- Study of the process of degradation of microplastics to nanoplastics under the influence of cold plasma. Determination of the effect of processing parameters on the degradation rate, analysis of changes in particle size and morphology.
- Determination of the mechanism of structural changes that occur as a result of oxidation under the influence of active particles formed as a result of plasma. Assessment of the kinetics of microplastic degradation.
- Assessment of the adsorption properties of activated carbon for the complete removal of microplastic degradation products. Study of changes in the pore structure, sorption capacity and sorption mechanism.
- Study of the effectiveness of cleaning organic pollutants in water using cold plasma technology. Determination of the degradation patterns and description of the mechanism of its chemical transformation.

The main provisions submitted for defense:

Cold plasma treatment intensively fragments the polymer chains of microplastics, breaking them down to nano-size. The size of melamine resin-based microplastic particles ranges from 2004±93 nm to 68±5,7 nm, and polystyrene particles from 1030±106 nm to 41±1,01 nm.

The mechanism of microplastic degradation is the cleavage of C=C and C–H bonds, oxidative destruction under the influence of active particles formed as a result of plasma, resulting in the formation of carbonyl groups (C=O). The concentration of microplastics in 1 ml of solution increases from 26630 (number of particles) to 78160 and is fragmented into small nanoparticles.

The specific surface area of nanostructured activated carbon: 28,1% and 31,3% reduction in micropore volume for walnut-derived activated carbon, and 34,9% and 20,8% reduction in micropore volume for coconut shell-derived activated carbon were due to the accumulation of nanoplastics, the decomposition products of nanotubes, on the surface. Thermogravimetric analysis showed that the mass loss of activated carbon in the range of 100–400 °C was due to the thermal destruction of adsorbed organic compounds.

Cold plasma decomposes the stable organic dye methylene blue with high efficiency - 100% in 25 minutes at pH 4, and in 30–35 minutes at pH 7 and pH 10.

Research object: cold plasma, microplastics and persistent organic pollutants, activated carbon.

Subject of the study : mechanisms of destruction of microplastics and organic pollutants (methylene blue) under the influence of cold plasma, processes of sorption of their decomposition products.

Research Methodology: During the dissertation work the following methods were used: transmission electron microscopy, cryo-TEM Hitachi ht7800, zeta potential and particle size analyzer, Malvern Nano Series (Malvern Instruments Limited, Malvern, UK), mass loss method, scanning electron microscopy, Hitachi s-4800 (Japan), BET (Brunauer–Emmett–Teller) sorption analyzer using Micromeritics Gemini VII (Micromeritics Instrument Corp, USA), Fourier transform infrared spectroscopy (FTIR) using a Nicolet is50 spectrometer (Thermo Fisher Scientific, USA), optical microscopy and statistical methods of experimental data processing. The results are based on the data obtained using reliable and accurate methods.

Scientific novelty of the study :

Cold plasma technology for microplastic degradation was tested for the first time and it was found that this method effectively degrades microplastics down to the nanoscale.

The reduction in the specific surface area and micropore volume of nanostructured activated carbon as a result of adsorption of microplastic degradation products demonstrated its ability to effectively filter nanoplastic fragments and proved the effectiveness of the adsorption mechanism.

The high efficiency of the plasma-chemical decomposition of organic pollutants using cold plasma was demonstrated.

The combination of cold plasma and sorption methods was proposed as a new environmentally friendly technology for the complete degradation of microplastics and the effective disposal of its processing products.

Application area: cleaning of water supply systems and circulation systems, cleaning of domestic wastewater.

Theoretical and practical significance of the work . This study contributes to the scientific understanding of the mechanisms of destruction of microplastics and persistent organic pollutants (methylene blue) under the influence of cold plasma. The research results allow us to theoretically substantiate the features of structural and chemical changes in microplastics under the influence of cold plasma, the patterns of formation of their decomposition products, as well as the influence of the main parameters of plasma treatment on the efficiency of destruction.

The research results will serve as the basis for the development of an integrated system combining cold plasma and activated carbon to improve water purification technologies. This technology ensures the effective removal of microplastics and persistent organic pollutants, minimizing their impact on the environment.

The reliability and validity of the results are primarily consistent with the observational data.

The reliability and validity of the results of the dissertation work is confirmed by the presence of publications in foreign journals with a high impact factor,

publications recommended by the Committee for Quality Assurance in Science and Higher Education of the Ministry of Science and Higher Education of the Republic of Kazakhstan, as well as materials from international scientific conferences.

Personal contribution of the author: The author took full part in the research work at all stages of the dissertation work: from numerical calculations to the choice of the research method. Discussion of reports and results was conducted jointly with the supervisors.

Dissertation approval:

in the journals recommended by the KOKNVO:

- Bexeitova K.S., Baimenov A.Zh., Zhantikeev U.E., Saulakhnauly E., Esin V.A., Mikhalovsky S.V., Azat S. Microplastic Pollution of Freshwater: Sources, Consequences, and Mitigation Strategies (Literature Review) // *Bulletin of the National Center of the Republic of Kazakhstan.* – 2024. – Issue. 1(97). – DOI: 10.52676/1729-7885-2024-1-34-44. – ISSN 1729-7516. – CC 34-43.

- Seymukhanova L.N., Zhantikeev U.E., Bexeitova K.S., Kunarbekova M.S., Rakhimova B.U., Kudaibergenov K.K., Azat S. Obtaining nanocellulose for water purification from dyes // *Bulletin of the National Research Center of the Republic of Kazakhstan.* - 2024. - Issue. 4 (December). - DOI: 10.52676/1729-7885-2024-4-181-190. - 10 p.

- Sapargali, I. O., Bexeitova, K. S., Zhantikeev, U. E., Nurgaliev, N. N., Azat, S. Comprehensive Method for Microplastic Removal from Water Using Sorbents // *Bulletin of Shakarim University. Technical Sciences*. — 2025. — No. 1(17). — P. 51–57. — DOI: 10.53360/2788-7995-2025-1(17)-51. — ISSN 2788-7995 (Print)

V base ah Scopus and Web of Science data:

Bexeitova K., Baimenov A., Varol E.A., Kudaibergenov K., Zhantikeyev U., Sailaukhanuly Y., Toshtay K., Tauanov Z., Azat S., Berndtsson R. Microplastics in freshwater systems: A review of classification, sources, and environmental impacts // Chemical Engineering Journal Advances. – 2024. – DOI: 10.1016/j.ceja.2024.100649. – JIF 5.5. – Q1. – CiteScore 8.3. – General Chemical Engineering – 83%. – 17 p.m.

- Bexeitova K., Zhantikeyev U., Yeszhan Y., Sapargali I., Kudaibergenov K., Toshtay K., Mikhalovsky S., Amrousse R., Berndtsson R., Azat S. Evaluating Microplastic Detection Techniques in Human-Impacted Water Systems: A Mini-Review // ES Energy and Environment. – 2024. – Volume 25. – DOI: 10.30919/esee1233. – CiteScore 10.7. – Environmental Engineering – 89%. – 15 s .

Kunasheva Z., Kubasheva R., Kuzmina R., Utepkalieva G., Erzhanova N., Aituganova S., Kiisheva D., Bexeitova K. Physical and Chemical Features of The Thermolysis of Wastewater Sludge // Engineered Science. – 2023. – ISSN: 2576-988X (Print), 2576-9898 (Online). – Q1, 98%. – DOI: 10.30919/es991. – 9 s .

- Askaruly K., Azat S., Sartova Z., Bexeitova K., Yeleuov M., Kerimkulova A. Obtaining and characterization of amorphous silica from rice husk // Journal of Chemical Technology and Metallurgy. – 2020. – ISSN 1314-7471. – CiteScore 1.2. – General Chemical Engineering – 32%. – 9 s .

- Sailaukhanuly Y., Popova A., Mansur T., Bexeitova K., Toshtay K.,

Tovassarov A., Tasmagambetova A. Preliminary Study and Assessment of Drinking Water from Almaty, Kazakhstan // Eurasian Chemico-Technological Journal. – 2022. – DOI: 10.18321/ectj1478. – ISSN 1562-3920. – JIF 0.655. – Q4. – CiteScore 1.4. – General Chemical Engineering – 29%. – 10 s .

Patent:

Azat S., Zhantikeev U.E., Bexeitova K.S., Tauanov Zh.K., Toshtay K., Sailauhanuly E., Kudaibergenov K.K. Method for obtaining a sorbent for water purification from microplastics // Patent for utility model No. 8598. – 03.11.2023. – 6 p.

Publications: The results of the dissertation work were published in 13 editions, including 5 articles included in the Scopus database, 3 publications in editions recommended by the Committee for Control in the Sphere of Education and Science of the Republic of Kazakhstan, 4 in international scientific collections, symposia and foreign conferences. 1 patent for a utility model was received.

Relationships with research and government programs:

№ AP14869499 " Plasma water purification for the decomposition of persistent polymeric and organic pollutants: from micro- to nanoparticles to molecules " - 2022-2024.

Volume and structure of the work: The dissertation is presented on 115 pages and consists of 37 figures and 17 tables. The work consists of an introduction, literature review, description of objects and methods of research, results and their discussion, conclusions, and a list of 144 references.