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DEVELOPMENT OF AN AUTONOMOUS INTELLECTUAL WASTEWATER TREATMENT SYSTEM BASED ON RENEWABLE ENERGY SOURCES

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Abstract: This study examines the scientific and technical foundations of developing an autonomous intelligent wastewater treatment system based on renewable energy sources. The proposed system integrates solar photovoltaic modules, an energy storage battery, electro-biological and membrane treatment modules, and a real-time monitoring and intelligent control system. It is intended to increase the efficiency of wastewater treatment and reduce specific energy consumption by controlling the main technological and energy parameters of the system. It is proposed to use artificial intelligence algorithms to determine the optimal operating mode of the treatment process based on parameters such as wastewater pH, temperature, turbidity, electrical conductivity, organic pollution indicators, membrane pressure, and water consumption. Coordination of energy production, accumulation, and consumption processes, taking into account the variability of solar energy, serves to ensure the autonomy of the system. The technological approach being developed will reduce dependence on the electricity grid, effectively use renewable energy, control membrane fouling, and increase the efficiency of deep wastewater treatment.

Keywords: wastewater, renewable energy, solar energy, photovoltaic module, autonomous system, electro-biological treatment, membrane treatment, artificial intelligence, intelligent control, energy efficiency, membrane fouling.

In modern industry and municipal services, effective wastewater treatment, reuse, and reduction of energy consumption of treatment processes are considered one of the important directions of sustainable development.[1] Wastewater generated by industrial enterprises contains organic and inorganic pollutants, suspended solids, mineral salts, heavy metals, and other chemical compounds, and reducing them to the established standards requires a complex multi-stage technological process.[2] At the same time, equipping traditional wastewater treatment plants with pumps, aeration devices, mixers, electrotechnological and membrane modules results in significant electricity consumption.

The high demand for electricity not only increases the operating costs of wastewater treatment systems, but also reduces the possibility of using such devices in areas with limited electricity supply.[3,4] Therefore, providing wastewater treatment processes with solar, wind and other renewable energy sources, as well as integrating energy production and water treatment processes into a single autonomous system, is an urgent scientific and technical issue.

Solar energy is one of the most promising renewable energy sources in this direction, allowing the direct production of electricity using photovoltaic panels.[5] By using a photovoltaic system in combination with an energy storage device, it is possible to ensure the operation of a wastewater

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treatment plant independent of the electrical grid. This approach is of great practical importance, especially for rural areas, small industrial enterprises, agroclusters and other remote facilities where there is no centralized electrical grid.

Mechanical, biological, electrocoagulation, adsorption and membrane technologies are widely used in wastewater treatment.[6] Although each of them is effective in reducing certain types of pollutants, achieving a high level of purification requires the use of several methods in sequence or in parallel. In particular, the electrocoagulation process is effective in separating colloidal and suspended particles, biological processes are effective in breaking down organic pollutants, and membrane technologies are effective in deep separation of dissolved substances and microorganisms.

Although the main advantage of membrane technologies is the ability to obtain high-quality purified water, the accumulation of contaminants on the membrane surface, i.e. membrane fouling, leads to a decrease in system efficiency and an increase in additional energy consumption.[7,8] Therefore, controlling the membrane operating mode in accordance with the current state of the wastewater and predicting its contamination in advance is of great importance in increasing the energy efficiency of the wastewater treatment system.

In recent years, the development of artificial intelligence and machine learning technologies has created new opportunities for automating and optimizing wastewater treatment processes.[9] Using artificial neural networks, fuzzy logic, and other intelligent algorithms, it is possible to determine complex nonlinear relationships between parameters such as wastewater pH, temperature, electrical conductivity, turbidity, organic pollution level, membrane pressure, water consumption, and energy consumption.[10] Based on this approach, it is possible to determine the optimal operating mode of the treatment process in real time, coordinate energy supply and technological load, and predict membrane fouling in advance. In particular, the creation of an intelligent control algorithm that takes into account the variable nature of renewable energy sources is important for ensuring the stable operation of an autonomous wastewater treatment system.[11,12]

At the same time, most of the existing research has considered renewable energy sources, integrated wastewater treatment technologies, and artificial intelligence-based control as separate systems.[13]

The issue of developing the scientific basis for an autonomous system powered by solar energy, combining electro-biological and membrane purification processes, and jointly managing energy and technological parameters based on artificial intelligence has not been studied in a sufficiently comprehensive manner.

Therefore, the main focus of this research is the integration of renewable energy sources, complex wastewater treatment technologies, energy storage, real-time monitoring and artificial intelligence-based control into a single autonomous intelligent water purification system.

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