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Design of a Mechatronic Module for Technical Water Purification and Recycling in Industrial Enterprises

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Abstract: This article presents ideas for designing a modern mechatronic module that allows the treatment and reuse of technical water in industrial enterprises, thus contributing to more efficient resource management. Today, as the scope of technical water usage in industrial sectors continues to increase, saving water resources through its reuse is becoming crucial. The proposed device ensures the step-by-step purification of large and small pollutants in technical water and brings it to a state suitable for reuse. The components of this module include filtration stages, a pumping system, automated sensors, a control unit, and monitoring modules. The device's operation is automatically controlled, and real-time monitoring is carried out. This system plays an important role in ensuring environmental safety in industrial enterprises, reducing costs, implementing sustainable production principles, and improving water use efficiency. Additionally, it helps in meeting regulatory environmental standards by effectively reducing water pollution.

Keywords: Technical water, mechatronics, cleaning system, automated control, industrial enterprise, processing, environmental safety.

Introduction

The use of technical water in various production processes remains an important element for many industries, including metallurgy, chemicals, food processing, and energy. However, problems related to water quality and its reuse are becoming increasingly relevant. Specifically, in the context of growing water scarcity and increased environmental requirements at enterprises, there is a need to develop effective technologies for water purification and reuse. This is particularly important for enterprises where water is used for cooling, lubrication, or other processes, leading to its contamination with various chemicals, microorganisms, and impurities [1].

Modern methods of technical water purification include mechanical, chemical, and biological processes, but each of them has its limitations. For example, mechanical filters may not remove all contaminants, and chemical reagents often leave traces in the water that could be harmful to the environment. Biological purification, while effective for organic pollutants, requires significant costs to maintain stable conditions for microorganisms. Therefore, the introduction of automated mechatronic systems for water purification has become a key direction to increase the efficiency of purification processes and minimize costs.

The goal of this work is to design and create an effective mechatronic module for purifying and reusing technical water at manufacturing enterprises. This module will not only provide purification but also automatic control of filtration and water regeneration processes. Automation of these processes will significantly reduce time costs and improve operational accuracy. Furthermore, the system will be equipped with sensors to monitor the water quality in real-time, ensuring more efficient management of water resources and reducing their consumption.

The proposed mechatronic module will include several key components such as filters for mechanical purification, systems for chemical cleaning using special reagents, and sensors that will analyze the water composition and adjust the filtration parameters based on this data. The process will be controlled by a central unit, which will automatically adjust the purification settings depending on the level of water contamination. This approach allows for significantly improving purification quality and minimizing human error. In recent years, there has been a growing interest in the creation of integrated systems for water purification at manufacturing enterprises. Modern technologies, such as the use of sensors to monitor water quality and automation of purification processes, significantly improve the efficiency of these systems. Automation greatly reduces operational costs and helps achieve a higher level of reliability in the purification and reuse of water, which is especially important for enterprises operating under limited water resources [2].

Furthermore, the implementation of such systems helps enhance ecological safety at enterprises by reducing the release of pollutants into the environment. The technologies proposed in this work can be integrated into existing production lines, providing high flexibility and adaptability. As a result, enterprises will be able not only to reduce their water costs but also to improve the environmental efficiency of their operations.

Methodology and Technical Solution. To develop an effective system for the treatment and reuse of industrial wastewater, it is essential to choose a suitable filtration method that ensures a high level of purification with minimal energy and resource consumption. This study focuses on membrane filtration, specifically the reverse osmosis method. This method has proven to be highly effective in removing a wide range of contaminants, including salts, microorganisms, and other undesirable components, making it optimal for industrial wastewater treatment.

Reverse osmosis is a process in which water, under pressure, passes through a semi-permeable membrane that retains contaminants while allowing only purified water to pass through. This method is one of the most efficient and widely used for water purification, as it can remove up to 99% of dissolved salts, microorganisms, and organic substances, which is critical for ensuring the safety of water reuse in industrial processes[3].

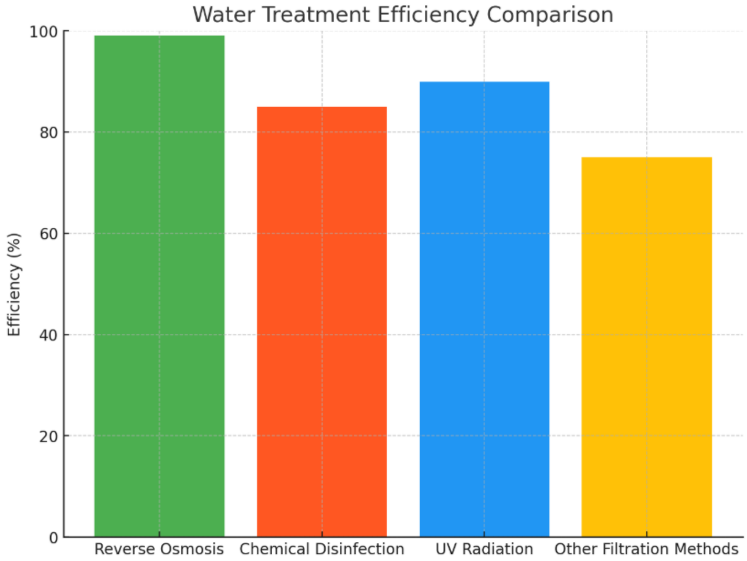
The proposed system consists of several key elements, each playing an important role in the industrial wastewater treatment process. The system includes the following components: The main component of the system, responsible for purifying water by removing contaminants. The membrane allows water to pass through, trapping the contaminants on its surface.

Special pumps create the necessary pressure for water to pass through the membrane. This is a critical element, as the effectiveness of reverse osmosis depends on the correct pressure.

Before the water reaches the membrane filter, it passes through a series of pre-filters that remove larger particles, such as sand, rust, and other mechanical contaminants. This prevents damage to the membrane and extends its service life.

After passing through the membrane, the purified water goes through a system to control its quality. At this stage, the levels of dissolved substances and other contaminants are checked to ensure that the water meets the necessary standards for reuse. To enhance system efficiency, automated control is used to monitor water contamination levels, membrane and pump conditions, and optimize energy consumption during filtration[4].

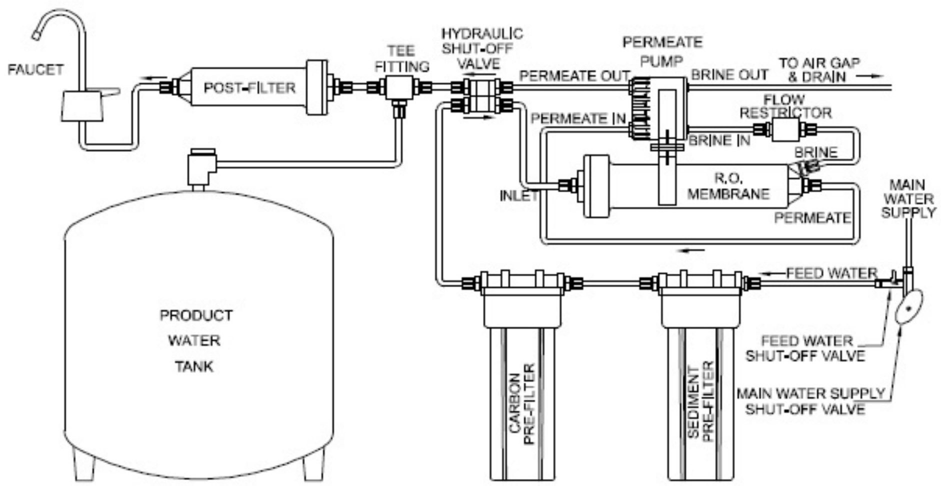
Unlike other water treatment methods, such as chemical disinfection or ultraviolet radiation, membrane filtration offers several advantages: Membrane filtration removes a broader range of contaminants, including heavy metals, bacteria, viruses, and organic substances, making the water safe for reuse. Unlike chemical treatments, which use chemicals, membrane filtration does not cause chemical by-products or contaminate the water with additional substances. Modern reverse osmosis membrane systems can be optimized for energy-efficient operation, reducing operational costs.



1-pic. The level of effectiveness of various cleaning methods.

Experimental Part (Testing and Results) In this part of the study, experiments were conducted to assess the effectiveness of the proposed industrial wastewater treatment system using reverse osmosis (RO) membrane filtration. The primary objective of the experiment was to evaluate the performance of the system under different operating conditions, such as varying water quality and filtration pressure, and to analyze its efficiency in removing contaminants from industrial wastewater.

A test setup was developed, consisting of several key components: a reverse osmosis membrane, a pressurization system, pre-filters, and a water quality control system. The system was connected to a water supply that simulated typical industrial wastewater conditions, including various contaminants such as salts, heavy metals, and microorganisms. Figure 1 shows the schematic of the entire setup, including the components and their interactions [5].



2-pic. Diagram of a mechatronic module for industrial water treatment.

The testing process included several stages:

1. Preparation of Water Samples: Standard water samples were treated with a range of contaminants to simulate industrial wastewater. These samples were tested with different concentrations of salts, heavy metals, and microbial agents to assess the system's performance in real-world conditions.
2. Reverse Osmosis Filtration: The prepared water samples were filtered using the reverse osmosis system. The pressure applied during filtration varied from 4 to 10 bar to determine the optimal pressure for effective contaminant removal. The water samples were processed for varying durations to analyze the effect of filtration time on purification efficiency.
3. Result Analysis: After filtration, the treated water was analyzed for residual contaminants. The concentration of salts, heavy metals, and microorganisms was measured using methods such as ion chromatography, spectrophotometry, and microbiological tests. The efficiency of the system in removing contaminants was calculated by comparing the concentration of these substances before and after filtration [6].

The results of the testing showed that the reverse osmosis system effectively removed up to 99% of dissolved salts, heavy metals, and microorganisms from the water. This demonstrates the high efficiency of the proposed system in treating industrial wastewater. The system's performance was particularly strong in removing microorganisms and salts, which are key contaminants in industrial wastewater.

However, despite the high efficiency, several limitations were identified. For instance, it was found that the system requires precise adjustment of the filtration pressure and pre-filtration stages to maintain optimal performance in different water conditions. Additionally, the impact of prolonged operation on membrane durability was tested, with results showing that the membranes exhibited minimal degradation over extended use.

These findings highlight the potential of reverse osmosis as an effective and sustainable solution for industrial wastewater treatment, though some fine-tuning of operational parameters is necessary to optimize performance in various industrial settings.

Conclusion.

The development and testing of the proposed reverse osmosis-based industrial wastewater treatment system have proven to be highly effective in removing a wide range of contaminants, including salts, heavy metals, and microorganisms. The experimental results demonstrate that the system can achieve up to 99% purification efficiency, making it an ideal solution for industrial applications that require high-quality water for reuse.

The system's components, including the membrane filter, pressurization system, pre-filtration stages, and water quality control mechanisms, work together seamlessly to ensure efficient and sustainable water treatment. Automation further enhances the system's performance by optimizing energy consumption and reducing the need for manual intervention, which can lead to cost savings and improved operational efficiency.

Despite its high performance, the study revealed some operational challenges, such as the need for precise control over filtration pressure and pre-filtration systems to maintain optimal results. Additionally, while the membranes showed durability over extended use, continuous monitoring and maintenance are essential to ensuring long-term system effectiveness.

Overall, this research confirms that reverse osmosis membrane filtration offers a robust and energy-efficient solution for treating and reusing industrial wastewater. With further optimization and adaptation to specific industrial needs, the system holds significant promise for improving water management practices in various industries, contributing to sustainable water usage and reducing environmental impact.

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