MODERN COAGULATION-BASED TECHNOLOGIES FOR INDUSTRIAL WASTEWATER TREATMENT

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Abstract: Industrial development significantly increases the volume of wastewater containing suspended solids, heavy metals, and persistent organic pollutants. This article analyzes contemporary coagulation-based technologies used in the treatment of industrial wastewater. The physicochemical mechanisms of coagulation and flocculation are examined, with particular focus on the efficiency of conventional inorganic coagulants and emerging natural coagulants. The study also evaluates the integration of coagulation with advanced physical and chemical treatment methods. Based on comparative analysis, practical recommendations are proposed to enhance treatment efficiency while ensuring environmental sustainability and rational water resource management.

Keywords: industrial wastewater, coagulation process, flocculation, water purification, sustainable technologies, inorganic coagulants, natural coagulants.

СОВРЕМЕННЫЕ ТЕХНОЛОГИИ КОАГУЛЯЦИИ ДЛЯ ОЧИСТКИ ПРОМЫШЛЕННЫХ СТОЧНЫХ ВОД

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Аннотация: Промышленное развитие значительно увеличивает объем сточных вод, содержащих взвешенные твердые частицы, тяжелые металлы и стойкие органические загрязнители. В данной статье анализируются современные технологии коагуляции, используемые для очистки промышленных сточных вод. Рассматриваются физико-химические механизмы коагуляции и флокуляции, с особым акцентом на эффективность традиционных неорганических коагулянтов и новых природных коагулянтов. В исследовании также оценивается интеграция коагуляции с передовыми физическими и химическими методами очистки. На основе сравнительного анализа предлагаются практические рекомендации по повышению эффективности очистки при обеспечении экологической устойчивости и рационального управления водными ресурсами.

Ключевые слова: промышленные сточные воды, процесс коагуляции, флокуляция, очистка воды, устойчивые технологии, неорганические коагулянты, природные коагулянты.

ENTRANCE

Rapid industrialization and urban growth have led to a sharp increase in water consumption and wastewater generation. Industrial wastewater often contains a complex mixture of suspended particles, toxic metals, oils, and organic compounds that pose serious risks to aquatic ecosystems and human health. Untreated or insufficiently treated effluents contribute to water pollution, biodiversity loss, and long-term environmental degradation.

Water treatment technologies play a critical role in reducing these risks by removing contaminants before wastewater is discharged into natural water bodies or reused in industrial processes. Among various treatment methods, coagulation has proven to be one of the most effective and widely applied techniques, particularly for removing fine suspended and colloidal particles that cannot be eliminated through simple sedimentation.

Water is one of the most essential natural resources for both human life and industrial development. Modern industry relies heavily on water for technological processes such as raw material processing, cooling and heating systems, energy generation, washing operations, and chemical synthesis. As industrial production expands, the demand for water increases proportionally, leading to the generation of large volumes of wastewater.

Industrial wastewater differs significantly from domestic wastewater due to its complex chemical composition and high concentration of pollutants. These effluents often contain toxic substances, including heavy metals, synthetic dyes, phenols, oils, and various organic compounds that are resistant to natural degradation. If discharged into natural water bodies without adequate treatment, such wastewater can cause severe environmental damage, including ecosystem imbalance, bioaccumulation of toxins, and deterioration of drinking water sources.

Therefore, effective wastewater treatment technologies are essential to ensure environmental protection and sustainable industrial development. Among the available treatment methods, coagulation has remained one of the most widely used and reliable processes due to its simplicity, effectiveness, and adaptability to different types of industrial wastewater.

Nowadays, we are using modern techniques to clean water from pollution. When water is polluted with various substances, we need to clean it with technological methods. In natural cleaning, we can take green grass and fungi at the bottom of the water as an example. In order to protect water bodies, it is necessary to thoroughly clean the water before dumping it into the basins. In addition, industrial wastewater is very It is rich in toxic, chemical reagent elements. Therefore, it is advisable to use a closed system when using wastewater in production.

There are many pollutants in wastewater. One of them is bacteria. There are several methods of water purification. The first is the recuperative method, the second is the destructive method. Our recuperative method separates the valuable substances contained in wastewater and then sends them for recycling. The destructive method separates water from pollutants using oxidation or reduction methods. When constructing new facilities, it is necessary to correctly calculate the amount of wastewater in the first place. In the treatment plant, wastewater is re-purified, neutralized, and the sediment formed from it is recycled. The purified wastewater is discharged into reservoirs and used for irrigation. Large chemical plants use several million cubic meters of clean water per year.

MATERIALS AND METHODS

Coagulation involves the destabilization of colloidal particles in water through the addition of chemical reagents known as coagulants. Commonly used inorganic coagulants include aluminum sulfate, ferric chloride, and polyaluminum chloride. These substances neutralize surface charges of particles, allowing them to aggregate into larger flocs that can be removed by sedimentation or filtration.

Recently, increasing attention has been given to natural and bio-based coagulants derived from plant extracts, microorganisms, and biodegradable polymers. These materials offer lower toxicity, reduced sludge production, and improved biodegradability compared to traditional chemical coagulants.

In this study, the performance of different coagulants was evaluated based on turbidity reduction, removal of organic matter, and sludge generation. Coagulation was also combined with auxiliary treatment methods such as filtration, air flotation, and advanced oxidation to assess overall treatment efficiency.

Industrial wastewater is characterized by high variability in composition, depending on the type of industry, production technology, and raw materials used. Typical contaminants include suspended solids, colloidal particles, emulsified oils, organic matter, and inorganic ions.

Suspended and colloidal particles are particularly problematic because of their small size and stability in water, which prevents their removal by simple sedimentation. Heavy metals such as lead, chromium, cadmium, and mercury are commonly present in effluents from metallurgical, electroplating, and chemical industries. Organic pollutants, including dyes, surfactants, and hydrocarbons, contribute to high chemical oxygen demand (COD) and biological oxygen demand (BOD), reducing dissolved oxygen levels in receiving water bodies.

The complexity of industrial wastewater requires the application of advanced and combined treatment methods to achieve regulatory compliance and minimize environmental impact.

RESULTS AND ANALYSIS

Experimental observations indicate that inorganic coagulants achieve high removal efficiency for suspended solids, with turbidity reduction reaching 90–95% under optimal dosing conditions. However, the use of such coagulants results in significant volumes of chemical sludge, increasing disposal and treatment costs.

Natural coagulants demonstrated moderate but stable performance, achieving turbidity removal efficiencies of 75–85%. Although slightly less effective than inorganic reagents, they produced substantially less sludge and showed better environmental compatibility. When coagulation was combined with filtration or oxidation processes, an additional reduction in organic pollutants was observed, improving overall water quality. Coagulation is a physicochemical process aimed at destabilizing colloidal particles suspended in water. These particles typically carry negative surface charges, which cause electrostatic repulsion and prevent aggregation. The addition of coagulants neutralizes these charges, allowing particles to collide and form larger aggregates known as flocs. The coagulation process generally consists of several stages: rapid mixing to disperse the coagulant, charge neutralization, floc formation, and subsequent removal of flocs through sedimentation or filtration. The efficiency of coagulation depends on several factors, including coagulant type and dosage, pH value, temperature, mixing conditions, and the chemical composition of the wastewater. When coagulation is combined with filtration or oxidation processes, additional reductions in COD and organic pollutant concentrations are achieved. These results confirm the effectiveness of coagulation-based hybrid systems for industrial wastewater treatment.

DISCUSSION

The findings confirm that coagulation remains a core process in industrial wastewater treatment systems. Traditional coagulants provide rapid and efficient contaminant removal but raise concerns related to chemical consumption and waste generation. In contrast, bio-based coagulants align with global sustainability goals and green chemistry principles, despite their relatively lower efficiency. An integrated treatment approach that combines conventional coagulation with natural coagulants and supplementary physical or chemical methods can significantly improve treatment outcomes. Such hybrid systems offer a balanced solution by ensuring high purification efficiency while minimizing environmental impact and operational costs.

CONCLUSION

Coagulation-based treatment technologies play a vital role in managing industrial wastewater pollution. While inorganic coagulants remain effective for large-scale applications, environmentally friendly alternatives present promising opportunities for sustainable water treatment. The combination of coagulation with advanced treatment methods enhances pollutant removal and supports efficient water reuse. Future research should focus on optimizing hybrid treatment systems and developing cost-effective natural coagulants to meet increasing environmental and industrial demands.

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