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Review on Industrial waste water treatment

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Abstract

Water is an essential natural resource that supports human life and maintains ecological balance. Rapid industrialization generates substantial amounts of wastewater containing toxic substances and harmful pollutants, which create serious risks for both the environment and public health. The nature of industrial wastewater differs significantly among industries in terms of volume, pollutant concentration, and contaminant composition. Therefore, understanding these variations is important for selecting suitable treatment technologies and designing efficient wastewater treatment systems that encourage sustainable water utilization. This paper reviews both traditional and modern wastewater treatment techniques while outlining their respective advantages and limitations. Furthermore, the study explores the possibility of combining multiple treatment methods to improve overall efficiency. This review discusses wastewater produced by different industrial sectors and highlights commonly used treatment approaches. In addition, the study examines the features, benefits, and limitations of physical, chemical, and biological wastewater treatment methods.

Keywords: *Wastewater treatment, industrial effluents, physical treatment, chemical treatment, biological treatment, water contamination, advanced treatment technologies.*

I. **INTRODUCTION -**Water plays a crucial role in sustaining ecosystems, supporting human survival, and driving agricultural and industrial development. As the global population continues to increase, the demand for freshwater resources is also rising. Around 97% of the Earth's water is saline, while only 3% is freshwater Water is an inorganic, transparent, odorless, tasteless, and nearly colorless substance that forms the foundation of life on Earth. It is the primary component of the Earth's hydrosphere and is present in all living organisms. Untreated wastewater pollutes rivers, lakes, and groundwater resources, causing eutrophication and threatening the health of plants, animals, and humans Scientists believe that life on Earth originally emerged from water. Industrial expansion has become a major contributor to water pollution through the release of significant amounts of industrial wastewater. This wastewater contains a complex mixture of contaminants such as organic and inorganic substances, heavy metals, toxic chemicals, and disease-causing microorganisms. Industrial wastewater treatment refers to the collection of techniques and processes used to treat wastewater produced during industrial and commercial operations. Once treated, the wastewater or effluent can be reused in industrial activities, discharged into municipal sewer systems, or safely released into natural water bodies. In many developed countries, industries have adopted practices to reduce wastewater generation and encourage recycling within production systems. According to the United Nations Environment Programme (UNEP), industrial activities are responsible for nearly 20% of global water pollution. The rapid growth of industrialization has therefore increased the urgency for effective wastewater management strategies. Since industries play a major role in degrading water quality, proper treatment and sustainable management practices are necessary to ensure environmental protection and water conservation. This review highlights the historical development and current status of industrial wastewater management while emphasizing the need for sustainable treatment approaches (Smith et al., 2020). Industrial processes generate a wide variety of pollutants, including heavy metals and organic contaminants, which can severely affect aquatic ecosystems and human health.

II.OVERVIEW OF WASTE WATER TREATMENT

Wastewater treatment plants (WWTPs) are generally developed to treat wastewater in an economical manner while ensuring that the treated water meets the required quality standards. In most cases, wastewater treatment involves a combination of different techniques applied in sequence, as each method is effective for removing specific types of contaminants. A typical wastewater treatment system is divided into four major stages: preliminary, primary, secondary, and tertiary treatment.

The preliminary treatment stage focuses on removing large solid materials, coarse particles, and grit from wastewater through processes such as screening, shredding, and grit separation. Following this, primary treatment is carried out to eliminate suspended solids, oils, grease, and remaining grit using methods like sedimentation and dissolved air flotation.

Secondary treatment mainly relies on biological processes to decrease the concentration of organic pollutants, nitrogen, and phosphorus present in wastewater. During this stage, microorganisms break down contaminants and convert them into biomass through various biochemical reactions.

The final stage, known as tertiary or advanced treatment, is used to further improve water quality so that the treated effluent can safely meet reuse or discharge standards. Advanced treatment technologies include membrane filtration, adsorption, and chemical oxidation processes.

Wastewater treatment methods are broadly categorized into physical, biological, and chemical techniques. Physical treatment methods involve processes such as screening, grinding, grit removal, sedimentation, dissolved air flotation, adsorption, ion exchange, and membrane filtration. Biological treatment processes are further classified into aerobic and anaerobic systems based on the presence or absence of oxygen. Chemical treatment methods include precipitation, coagulation, flocculation, evaporation, distillation, membrane distillation, solvent extraction, electrochemical treatment, chemical oxidation, and advanced oxidation processes (AOPs). Each treatment method possesses distinct characteristics along with specific advantages and limitations.

III. TYPES OF TREATMENT

(i) Preliminary Treatment

(ii) Primary treatment.

(iii) Secondary treatment.

(iv) Tertiary treatment

A. PRELIMINARY TREATMENT

Wastewater treatment starts with preliminary treatment, it is designed to remove large floating materials, coarse solids, and grit. This stage typically involves operations such as screening, size reduction, and grit removal to protect downstream equipment. Screening is a preliminary treatment process in which a screen with uniformly sized openings is used to capture and remove large debris, such as cloth, plastics, paper, and other coarse materials from wastewater. Screens with openings of up to 10 mm are commonly used for this purpose. Sedimentation is a physical treatment process that relies on the force of gravity to separate and remove suspended particles from wastewater. As the water remains undisturbed, heavier solids settle at the bottom, resulting in clearer water.

B. PRIMARY TREATMENT

Primary treatment is carried out after the preliminary treatment stage and is mainly intended to remove settleable suspended solids (SS) from wastewater. Under normal gravity settling conditions, approximately 60% of suspended solids can be removed without the addition of chemicals. During this process, a small amount of dissolved and colloidal matter is also eliminated along with the settled solids, although this is not the primary objective. The treatment is performed in primary clarifiers, where wastewater is retained under calm hydraulic conditions to allow heavier particles to settle by gravity. These settled materials accumulate at the bottom of the tank as primary sludge. To ensure efficient settling,

In large treatment plants, mechanical scrapers installed at the base of the clarifier continuously move the accumulated sludge toward a collection hopper, from which it is pumped to the sludge treatment unit. The clarified effluent leaves the tank by flowing over outlet weirs, which are generally located around the perimeter of the clarifier. In some designs, the effective weir length is increased by extending the outlet launder away from the tank wall using support brackets to maintain the desired overflow rate.

Large sewage treatment plants (STPs) commonly use circular or rectangular clarifiers**,** whereas smaller facilities may employ circular or square settling tanks. In most STPs, both primary and secondary clarification rely solely on gravity and are carried out without chemical additives. However, when coagulants are introduced, the treatment efficiency improves significantly, with suspended solids removal reaching up to 90% and BOD_5 reduction of approximately 70%**.** Despite these advantages, the routine use of coagulants in large-scale municipal wastewater treatment is generally limited because of higher operational costs and the increased production of chemical sludge.

C. SECONDARY TREATMENT

Secondary treatment is the stage that follows primary treatment and is designed to remove the dissolved and colloidal organic matter that remains in wastewater. This stage primarily relies on biological processes, in which microorganisms break down biodegradable pollutants and convert them into stable biomass, water, and carbon dioxide. The most widely used biological process in sewage treatment is the activated sludge process, an aerobic suspended-growth system where microorganisms remain suspended in the mixed liquor inside an aeration tank. Depending on the treatment requirements, the reactor may be designed as a complete-mix, plug-flow, or intermediate-flow system. Common activated sludge process configurations include the high-rate activated sludge, conventional activated sludge, and extended aeration systems. These process configurations mainly differ in terms of their hydraulic retention time (HRT) and cell residence time (CRT). High-rate activated sludge systems operate with the shortest HRT and CRT, enabling them to treat larger volumes of wastewater within the same reactor size. In contrast, extended aeration systems require longer retention times, making them less hydraulically efficient but generally more stable and easier to operate under varying loading conditions.

Several modified forms of the activated sludge process are also available. For example, the oxidation ditch and aerated lagoon are both extended aeration systems but differ in reactor design and flow characteristics. Regardless of the configuration, biological reactors are typically followed by secondary clarifiers, where biological solids settle under gravity. The clarified effluent usually contains 50 mg L^{-1} or less of suspended solids, while the settled biomass, known as return activated sludge (RAS), is recycled back to the aeration tank to maintain an adequate concentration of mixed liquor suspended solids (MLSS) for efficient biological treatment.

In addition to suspended-growth systems, attached-growth processes are also widely used in wastewater treatment. Examples include trickling filters and rotating biological contactors (RBCs). In these systems, microorganisms develop as a biofilm on specially designed support media that provide a large surface area for microbial attachment. In trickling filters, wastewater flows over the biofilm while air supplies the required oxygen. In rotating biological contactors, the support discs rotate alternately through wastewater and the atmosphere, allowing microorganisms to receive both nutrients and oxygen. Another advanced biological treatment method is the integrated fixed-film activated sludge (IFAS) process, which combines suspended-growth and attached-growth technologies within the same reactor. In IFAS systems, biofilm carriers remain continuously submerged in the aeration tank, increasing the microbial population and improving treatment efficiency. Aeration is usually concentrated beneath the carrier media to ensure sufficient oxygen transfer for both suspended and attached microorganisms.

Following biological treatment, wastewater passes into a secondary clarifier, where microbial biomass is separated from the treated water by sedimentation. A portion of the settled sludge is returned to the biological reactor to sustain microbial activity, while the excess sludge is removed for further treatment. The clarified effluent may then be discharged into a receiving water body or transferred to tertiary treatment if additional purification is required to meet discharge or reuse standards.

D. TERTIARY TREATMENT

Tertiary treatment is the final stage of wastewater treatment and is carried out to further improve the quality of the treated effluent before it is reused, recycled, or discharged into the environment. The main objective of this stage is to eliminate the remaining contaminants that are not effectively removed during primary and secondary treatment.

This advanced treatment process targets residual nutrients, particularly nitrogen and phosphorus**,** as well as fine suspended particles and other inorganic substances. It also provides effective removal or inactivation of harmful microorganisms, including bacteria, viruses, and parasites**,** thereby reducing potential public health risks.

Chemical coagulants such as alum (aluminium sulfate) are commonly added to enhance phosphorus removal and promote the aggregation of fine particles into larger flocs, which can then be easily separated through filtration. Following filtration, the treated wastewater undergoes **disinfection**, typically in chlorine contact tanks, where chlorine is applied to destroy any remaining disease-causing microorganisms.

Before the treated effluent is released into natural water bodies or reused, any residual chlorine is neutralized using sodium bisulfite. This dechlorination step prevents harmful effects on aquatic ecosystems and ensures that the discharged water meets environmental quality standards.

IV. CONCLUSION

The major concerns associated with wastewater reuse are primarily linked to inadequate or insufficient treatment before its application. Therefore, there is a need to develop affordable, simple, and user-friendly treatment solutions that can protect wastewater-dependent livelihoods while preventing the degradation of valuable natural ecosystems. Consequently, achieving safe, sustainable, and well-planned wastewater reuse requires comprehensive policy support and integrated programs that promote decentralized low-cost treatment systems, biofiltration technologies.

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