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A COMPREHENSIVE REVIEW ON APPLICATIONS OF BIOREACTORS AND AI TOOLS USED IN WASTEWATER TREATMENT FOR ENVIRONMENTAL PROTECTION

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Abstract

Wastewater is the water which is contaminated that cannot be used for drinking purposes and it may cause serious diseases. This wastewater needs to be treated to make it less harmful for use. Bioreactors promote the growth of microorganisms that break down the pollutants present in the wastewater. Various types of bioreactors like activated sludge bioreactor, anaerobic bioreactors SBRs, MBRs and MBBRs can be used for wastewater treatment. These bioreactors play crucial role in meeting regulatory standards and promoting sustainable water management practices in both municipal and industrial wastewater treatment facilities. In industrial wastewater treatment, activated sludge reactor, sequential bioreactors and membrane bioreactors treat the wastewater. There are various emerging contaminants that must be reduced for the protection of the water i.e. microplastics, nanoparticles and various endocrine disrupting compounds. Today, researchers are introducing eco-friendly bioreactors for better environment. In future, there is a need to make these bioreactors economically better, so that they can be used everywhere for the cleanliness of water.

INTRODUCTION

Wastewater refers to used water from various sources, such as household use, industrial waste and agriculture that contain contaminants and pollutants. This wastewater contain chemicals, pathogens and organic matter (M. Henze, Comeau, & design, 2008). Proper treatment of wastewater is vital to prevent environmental pollution and also help in protection of water. Waste treatment is the critical aspect of maintaining water resources and ecosystem health (Gray, 2004). The purpose of wastewater treatment is to remove contaminants and pollutants from wastewater, making it safe for discharge into the environment or for reuse (Droste & Gehr, 2018). The role of bioreactors in wastewater treatment is to provide a biologically active environment where microorganisms can break down and remove contaminants from the wastewater. This process helps to improve the quality of the wastewater, making it suitable for discharge or reuse (M. Henze, van Loosdrecht, Ekama, & Brdjanovic, 2008). Bioreactors are used in various applications, including wastewater treatment, where they help to break down and remove contaminants from the wastewater (Dhote, Ingole, & Chavhan, 2012). The microorganisms in the bioreactor consume the contaminants in the wastewater, breaking them down into harmless substances. This process helps

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to improve the quality of the wastewater, making it suitable for discharge or reuse.

Basics of wastewater treatment

The composition of wastewater is 99% water and the remaining 1% is solid content being added by using water. The solid material consists of organic matter, inorganic compounds and microorganisms (Sonune & Ghate, 2004). Generally, types of wastewater are gray water that comes from baths, showers, washing machines, basins and kitchens and black water that comes from toilets (Bitton, 2005). Both gray and black water forms sewage. It helps to prevent adverse effects caused by treating it with chemicals as chemicals accumulate in water bodies. It is cost effective, environment friendly and safe. It is efficient in removing organic matters.

DEFINITION OF BIOREACTORS

Bioreactors are fermentation vessels that are used for biological and chemical processes. It is a closed container that provides adequate features for water treatment and removal of waste biomass as well as their waste products (Lidén & engineering, 2002). A bioreactor is a specially designed chamber that supports a biologically active environment, where bacteria and protozoa (biomass) can grow and consume some or all of the wastewater components (Van't Riet & Tramper, 1991). Bioreactors are used in various applications, including wastewater treatment, where they help to break down and remove contaminants from the wastewater. Bioreactors are controlled environments designed to support biological processes, often used in various applications ranging from industrial processes to environmental protection (Al-Asheh, Bagheri, Aidan, & Engineering, 2021). In wastewater treatment, bioreactors utilize microorganisms to break down organic pollutants, converting them into less harmful substances.

ROLE OF BIOREACTORS IN WASTEWATER TREATMENT

Bioreactors play vital role in wastewater treatment with the help of the microorganism to break down the pollutants. Sewage and industrial effluents are treated by using these reactors (Narayanan & Narayan, 2019). Bioreactors enhance water quality and are essential components in wastewater treatment plants. Bioreactors promote the growth of microorganisms, such as bacteria and fungi that naturally consume and break down organic pollutants which are present in wastewater (Narayanan & Narayan, 2019). Bioreactors can be used for the removal of nutrients like nitrogen and phosphorus, by reducing the risk of nutrient-related environmental problems such as algal blooms (Deowan et al., 2019). Microbial biomass generated in bioreactors contributes to the treatment process by adsorbing and absorbing impurities, aiding in their removal. Moreover, a common bioreactor method, the activated sludge process involves aerating wastewater to encourage microbial activity, forming a sludge that settles and separates from the treated water (Shim, Yoo, & Lee, 2002).

TYPES OF BIOREACTORS USED IN WASTEWATER TREATMENT

Various types of bioreactors are employed in wastewater treatment, each with specific features catering to diverse treatment needs (Shanmugam, Mandari, Devarai, & Gummadi, 2022). Each type of bioreactor has its advantages and is selected based on factors like the type and strength of wastewater, space availability, treatment goals, and operational considerations in wastewater treatment plants (Spier, Vandenberghe, Medeiros, Soccol, & applications, 2011). Following types of bioreactors are extensively used.

ACTIVATED SLUDGE BIOREACTOR

The activated sludge bioreactor is an important component in wastewater treatment, employing a sophisticated biological process to effectively remove contaminants (Sakai, Fukase, Yasui, Shibata, & Technology, 1997). In this system, wastewater is mixed with a culture of microorganisms in an aerated tank, creating a suspended mass of microbial flocs or flacks known as activated sludge (Liu & Tay, 2001). These microorganisms, primarily bacteria, play a crucial role in breaking down organic pollutants present in the wastewater. For the promotion of the

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growth of bacteria that consume and digest organic matter, the aeration process provides the necessary oxygen for microbial metabolism (Eckenfelder, 1998). After the aeration phase, the activated sludge undergoes a settling process, which allows the microbial flocs to settle down at the bottom of the tank (M. J. W. S. Henze & Technology, 1992). The treated water, which is now mostly free of pollutants, is then separated from the settled sludge. Return activated sludge, is recycled back into the influent to ensure a constant population of active microorganisms to maintain a stable and efficient system, a portion of the settled sludge (Sustarsic, 2009).

This recycling, along with periodic removal of excess sludge, contributes to the feasibility and continuous operation of the activated sludge bioreactor (Sustarsic, 2009). The versatility and effectiveness of this bioreactor make it a cornerstone in modern wastewater treatment plants, facilitating the removal of organic contaminants and promoting the purification of water resources in an environmentally responsible manner. The activated sludge process stands as a testament to the power of controlling microbial activities for the sustainable treatment of wastewater, demonstrating its significance in ensuring the health of ecosystems and safeguarding public water supplies (Gernaey et al., 2004).

SEQUENCING BATCH REACTORS

Sequencing Batch Reactors (SBRs) are advanced wastewater treatment systems designed for efficient and flexible operation (Mahvi, 2008). These reactors combine various treatment stages in a single tank, functioning in sequential cycles. In a Sequencing Batch Reactor cycle, wastewater undergoes aeration, where microorganisms break down organic matter (M. Singh & Srivastava, 2011). Following aeration, the system enters a settling phase, allowing biomass to settle at the bottom, separating it from the treated water. The clarified effluent is then discharged or subjected to further treatment to make it more pure. SBRs offer various significances like nutrient removal, flexibility in handling variable flow rates, and the ability to adapt to transforming treatment needs (Dutta & Sarkar, 2015). Their cyclical nature allows for optimal biological treatment and aeration, contributing to enhanced pollutant removal efficiency. As a versatile and space-efficient solution, sequencing batch reactors find widespread use in wastewater treatment plants, providing effective and adaptable means to address the challenges of varying influent characteristics and stringent water quality standards (Showkat & Najar, 2019).

ANAEROBIC BIOREACTORS

Anaerobic bioreactors are integral components of wastewater treatment systems, employing a biological process in the absence of oxygen to break down organic matter (Skouteris, Hermosilla, López, Negro, & Blanco, 2012). In these reactors, anaerobic microorganisms, predominantly bacteria, facilitate the decomposition of organic pollutants, converting them into gases such as methane and carbon dioxide (Vinardell et al., 2020). Common designs include up flow anaerobic sludge blanket (UASB) reactors and anaerobic sequencing batch reactors (ASBR) (Bodkhe, 2008). Anaerobic treatment has several advantages, including reduced energy consumption compared to aerobic processes, and the generation of biogas as a byproduct that can be harnessed for energy. Anaerobic bioreactors are particularly effective in treating high-strength organic wastewaters, such as those from food processing industries. However, they may require longer retention times and careful monitoring to optimize performance. Anaerobic bioreactors contribute significantly to sustainable wastewater treatment practices by harnessing microbial activities in the absence of oxygen, minimizing energy requirements, and facilitating the recovery of valuable resources from wastewater (Chan, Chong, Law, & Hassell, 2009).

MEMBRANE BIOREACTORS

Membrane Bioreactors (MBRs) are advanced wastewater treatment systems that integrate biological treatment with membrane filtration. These reactors enhance solid-liquid separation, producing high-quality effluent (Melin et al., 2006). The distinguishing feature of MBRs is the

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use of semi-permeable membranes, typically microfiltration or ultrafiltration membranes, to separate solids from the treated water. This eliminates the need for secondary clarification processes. MBRs employ microorganisms to break down organic pollutants in wastewater through aerobic processes, similar to traditional activated sludge systems (Le-Clech & biotechnology, 2010). The membrane barrier ensures a consistently high-quality effluent by preventing the passage of suspended solids and bacteria. This makes MBRs particularly effective in meeting stringent water quality standards. Despite their advantages, MBRs may face challenges such as membrane fouling, which requires regular maintenance and cleaning. Nevertheless, their ability to produce treated water of superior quality and their compact design make Membrane Bioreactors a popular choice in various wastewater treatment applications, including industrial and municipal settings.

MOVING BED BIOFILM REACTORS

Moving Bed Biofilm Reactors (MBBRs) are innovative wastewater treatment systems that utilize suspended plastic biofilm carriers to foster the growth of microorganisms involved in the biological treatment process. In MBBRs, these carriers move freely within the reactor, creating a dynamic environment that enhances contact between microorganisms and the wastewater (Ødegaard, Rusten, Westrum, & Technology, 1994). As the biofilm-covered carriers circulate, they provide a large surface area for the attachment and growth of bacteria, which break down organic pollutants in the wastewater (McQuarrie & Boltz, 2011). The continuous motion helps prevent biofilm sloughing and allows for the effective treatment of various types of wastewater, including municipal and industrial effluents. MBBRs offer advantages such as flexibility, high treatment efficiency, and the ability to handle variations in organic loads, making them a versatile and widely adopted solution in modern wastewater treatment plants (Dezotti et al., 2018). The primary benefit of MBBR is its ability to concentrate suspended and biofilm biomass in one operational unit while permitting a notably higher density of biomass in the system.

A full-scale MBBR system used to treat industrial effluent from DPG manufacture was observed in operation for five years (Leyva-Díaz, Martín-Pascual, Poyatos, & technology, 2017). Thanks to MBBR technology, industrial wastewater that had previously undergone extremely inefficient treatment could now be handled properly. Currently, the two main contaminants—aniline and cyanides—have been successfully removed. Each time, the concentration of cyanide wastewater was less than the maximum permitted amount. The MBBR system is now almost entirely waste-free because of the way it was implemented, which also reduced the amount of waste sludge and industrial wastewater effluents produced.

APPLICATIONS OF BIOREACTORS IN WASTEWATER TREATMENT

Bioreactor utilizes biological processes, which break down organic pollutants with the help of microorganisms from the wastewater. Bioreactors play a crucial role in mitigating environmental impacts, meeting regulatory standards, and promoting sustainable water management practices in both municipal and industrial wastewater treatment facilities. The applications of bioreactors in different wastewater treatments are as followed,

INDUSTRIAL WASTEWATER TREATMENT

Industrial wastewater treatment is a critical process aimed at removing contaminants from water produced by industrial activities before its release into the environment or reuse (Ng, 2006). The characteristics of industrial wastewater vary widely depending on the industry, and treatment methods are tailored accordingly for environmental protection (Marrot, Barrios-Martinez, Moulin, & Roche, 2004).

Activated Sludge Process

Bioreactors are mostly used in the activated sludge process, which is a major method for biological treatment (Kayser & Applications, 2005). In this process, wastewater is mixed with a microbial

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culture called activated sludge, which consists of microorganisms such as bacteria and protozoa (Eckenfelder & Musterman, 1998). The mixture is aerated to provide oxygen, causing the growth of microorganisms that consume and break down organic pollutants in the wastewater of the environment. The mixture undergoes sedimentation to separate the treated water from the activated sludge after the biological treatment (Melcer, 2004).

Sequential Batch Reactors (SBR)

The sequential batch reactor (SBR) is a fill and draw activated sludge system for wastewater treatment. In this system, wastewater is added to a single batch reactor, treated to remove undesirable parts, and then discharged (Suresh, Tripathi, Gernal, & Management, 2011). Equalization, aeration, and clarification can all be achieved using a single batch reactor. To enhance the performance of the system, two or more batch reactors are used in a predetermined sequence of operations (Altaf & Ali, 2010). SBR systems have been successfully used to treat both municipal and industrial wastewater. They are uniquely suited for wastewater treatment applications characterized by low or intermittent flow conditions (Neczaj, Kacprzak, Kamizela, Lach, & Okoniewska, 2008).

Anaerobic Bioreactors

Anaerobic Digestion is the biological degradation of organic matter with the subsequent converting of chemical energy in organic carbon into biogas in the absence of oxygen (Vinardell et al., 2020). Normally, Anaerobic Digestion has been used with wastewater sludge treatment and reduction, agricultural, and food waste management. To complete more sustainable resource recovery and reduce the overall energy footprint, wastewater can be regarded as a renewable resource for converting embedded chemical energy into biogas. For industries producing high-strength organic wastewater, anaerobic bioreactors provide a well-organized solution for this. Anaerobic digestion by microorganisms like bacteria in the absence of oxygen bring out biogas, which can be employed for energy generation.

Membrane Bioreactors (MBR)

MBRs combine biological treatment with membrane filtration using bioreactor (Stephenson, Brindle, Judd, & Jefferson, 2000). Microorganisms treat the wastewater in a bioreactor, and the treated water which do not contain any contaminants is separated from the biomass using membranes. This stamp out the need for a separate clarification step. MBRs are mostly used for treating industrial wastewater that contain high levels of solids (di Biase, Kowalski, Devlin, & Oleszkiewicz, 2019).

Table 1. Differences between the types of bioreactor in industrial wastewater treatment

Bioreactor Type	Description	Key Features	Applications	References
Activated sludge process	Mixes wastewater with microbe culture and separates treated water from sludge	Aeration, sedimentation, microbial culture	Municipal and industrial wastewater treatment	
Sequential Batch Reactors (SBR)	Fill and draw system with single or multiple batch reactors	Equalization, aeration, clarification in single reactor, flexible operation	Municipal and industrial wastewater treatment	
Anaerobic Bioreactors	Biodegradation of organic matter without oxygen, producing biogas	Anaerobic digestion, biogas production, energy generation	Organic wastewater, agriculture and food waste management, industrial wastewater treatment	

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Membrane Bioreactors (MBR)	Combines biological treatment with membrane filtration	No separate clarification step, high solid removal, compact design	Industrial wastewater treatment	

MUNICIPAL WASTEWATER TREATMENT

Municipal wastewater treatment is a critical process aimed at safeguarding public health and the environment by effectively treating and purifying sewage and other wastewater generated within communities (Sikosana, Sikhwivhilu, Moutloali, & Madyira, 2019). Municipal wastewater treatment plays a pivotal role in preventing waterborne diseases, protecting ecosystems, and ensuring the sustainable use of water resources, contributing significantly to public and environmental well-being (Roeleveld et al., 1997). Advanced treatment methods, including filtration, disinfection, and nutrient removal, follow to achieve high-quality effluent (Jetten, Horn, van Loosdrecht, & technology, 1997). The treated water is then discharged into receiving water bodies or, increasingly, reclaimed for non-potable purposes (Negulescu, 2011).

Conventional Activated Sludge Plants

The activated sludge process is a conventional biological process that is used for the reduction of wastewater in which organic matter are present in. It involves the oxidation of carbonaceous biological matter, for reduction of the organic pollutants (Gerba & Pepper, 2019). The process takes advantage of aerobic micro-organisms that can digest organic matter in wastewater, and are then wasted as sludge, the non-active microbes are later removed from the system.

Trickling Filter Bioreactors

Trickling filters involve the use of bioreactors, typically beds of media, over which wastewater trickles and then it is treated for later use (Naz, Saroj, Mumtaz, Ali, & Ahmed, 2015). Microorganisms attached to the media surface treat the wastewater as it passes through it. The natural or forced aeration in the trickling filter promotes the growth of microorganisms and facilitates the breakdown of organic pollutants which results in the treatment of water (Daigger & Boltz, 2011). The hydraulic loading rate of contemporary trickling filters is regulated to preserve a consistent thickness of the biofilm layer. Additionally essential to a trickling filter's successful operation is a sufficient air flow. Natural aeration is the primary cause of airflow, with the temperature differential between the air inside the filter and the surrounding air acting as a catalyst.

A non-submerged fixed film biological reactor with plastic or rock support material is called a trickling filter. The average depth of the support media is 1.8 meters, with a range of 0.9 to 2.5 meters. Typically, filter beds are circular, and a rotary distributor spreads the liquid effluent across the top of the bed. Almost all recently designed trickling filters are made of plastic media. Plastic media trickling filters come in a variety of shapes and sizes, with depths ranging from 4 to 12 meters. The trickling filter also consists of an underdrain, a structure to hold the media, and a wastewater dosing or application mechanism in addition to the support medium. Compared to rock-based filters, modern trickling filters with plastic support material can achieve superior results, but at a significantly higher cost.

Rotating Biological Contactors (RBC)

A rotating biological contactor (RBC) is a type of attached-growth biological wastewater treatment system and a popularly used biological wastewater treatment technology (Hassard et al., 2015). It employs a series of rotating discs to support the growth of microbes and promote the removal of pollutants from wastewater (Waqas et al., 2021). One remediation technique utilized in wastewater secondary treatment is revolving biological contactors. With this approach, pollutants are removed more easily by letting wastewater interact with a biological medium. 1929 saw the publication of one of the first papers on the treatment of wastewater using a contact technique with rotating plates that were partially immersed. Nevertheless, a commercially viable method wasn't made accessible until 1965. A rotating biological contactor (RBC) can be found in many various

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designs nowadays, but in its most basic version, it is just a set of discs positioned on a shaft that is powered to rotate the discs at an angle of 90 degrees to the flow of settled sewage. Typically composed of plastic (polythene, PVC, or expanded polystyrene), the discs are housed in a trough with around 40% of their surface submerged. Baffles are placed between each set of discs when they are organized in groups or packs to reduce surging and short circuiting. Large units are frequently housed within buildings, whereas tiny units have their trough covered. By doing this, the impact of weather on the active biofilm that adheres to the disc surfaces will be lessened.

EMERGING CONTAMINANTS AND BIOREACTOR SOLUTION

The term "emerging contaminants" refers to pollutants not conventionally monitored in wastewater, including pharmaceuticals, personal care products, and industrial chemicals (Taheran et al., 2018). Bioreactors offer promising solutions for addressing these emerging contaminants:

Pharmaceuticals and Personal Care Products (PPCPs)

Pharmaceuticals and personal care products (PPCPs) are considered as the group of compounds that can be cosmetics ingredients, food supplements, and pharmaceutical drugs along with their byproducts. Bioreactors, especially those employing advanced microbial consortia, have shown efficiency in degrading PPCPs (Daughton & Ternes, 1999). These microbes can metabolize and change these contaminants into less harmful substances (Ellis, 2006). Furthermore, some bioreactors have biofilms that allows microbes to stick and grow that helps in the increase of efficiency of degradation of PPCPs. Bioreactors are considered good solution because they can be operated under both conditions, with or without oxygen and offer optimization of factors like pH, temperature and nutrient supply that can increase degradation of PPCP.

Microplastics

Microplastics are a growing concern in wastewater. Bioreactors with specialized microorganisms or fungi have been put forwarded to break down microplastics into smaller fragments, facilitating their ultimate mineralization (Andrady, 2011).

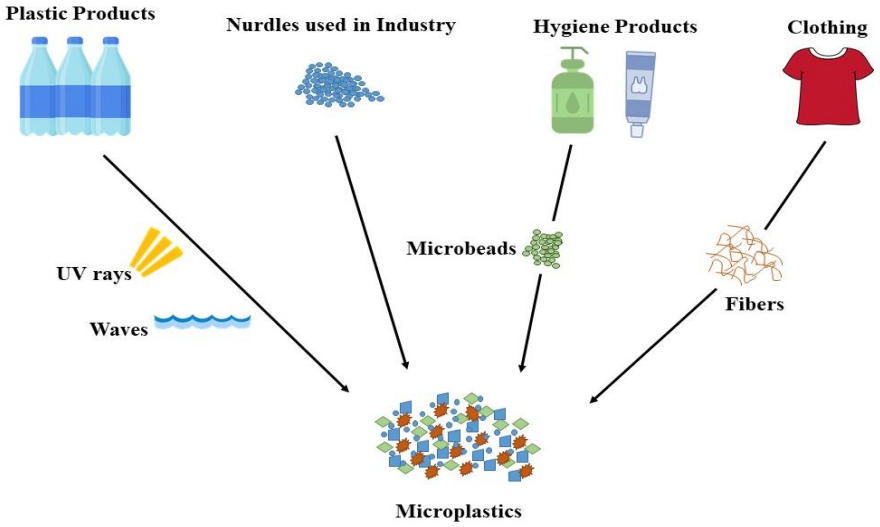


Figure 1. Sources of microplastics used in daily life activities present in environment

Endocrine-Disrupting Compounds (EDCs)

EDCs can interfere with hormonal systems in aquatic organisms and humans (Auriol, Filali-Meknassi, Tyagi, Adams, & Surampalli, 2006). Bioreactors can aim at these compounds through various biological processes, such as sorption, transformation, and degradation.

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Nanoparticles

Engineered nanoparticles used in various industries create challenges in wastewater treatment. Bioreactors with modified microbial communities can play an important role in breaking down or immobilizing these nanoparticles (Biswas, Wu, & association, 2005; Jou & Huang, 2003).

APPLICATIONS OF AI TOOLS IN WASTEWATER TREATMENT

With the advancement of the growing world, Artificial intelligence is taking rule over the world. In wastewater treatment, Ai tools are used for the anomaly detection, process optimization and predictive maintenance (Zhang et al., 2023). Ai tools are more efficient and optimized as compared to the other tools. These tools also reduced energy consumption and enhanced overall wastewater treatment process (Fernando, Khadaroo, Poh, Challenges, & 4.0, 2022).

PREDICTIVE MAINTENANCE

Predictive maintenance using Artificial intelligence has revolutionized treatment of wastewater by enabling proactive measures to maintain treatment efficiency (Malviya & Jaspal, 2021). This approach also increase the life of useful components and prevent the unnecessary wear and tear. With the advancement of technology, predictive maintenance with the help of Ai will become more efficient for wastewater treatment plants (Nourani, Elkiran, Abba, & Technology, 2018). Ai predictive maintenance system use advanced algorithms to analyze the history of the wastewater, read out the sensors and other operational parameters (Nourani et al., 2018). By monitoring these, issues are detected like pipe blockage or pump failures by machine learning algorithms to make wastewater able for treatment process (Zhao et al., 2020).

QUALITY MONITORING

Water quality monitoring is a crucial technique for obtaining water quality metrics or data when using AI models in WWT (Altowayti et al., 2022). Sensors are used to continuously check the quality of influent and effluent water, yielding a wealth of data. Certain water quality parameters are readily obtained and used as inputs for AI models when monitoring influent water, such as BOD, COD, pH, DO, flow rate, temperature, and initial pollutant concentration (Ntalaperas et al., 2022). On the other hand, when monitoring effluent water, certain water quality parameters are typically employed to assess the efficacy of wastewater treatment plants (WWTPs) or the impact of WWT (Bhagat, Tung, & Yaseen, 2020). Data-driven modelling and real-time prediction have become more appealing due to the proliferation of measurable data, AI models, and multivariate statistical techniques. Approach can detect micro pollutants that cannot be monitored using the monitoring techniques used by WWTPs, exceed detection limits, and produce high-precision measurement findings. A promising real-time monitoring tool for image recognition in WWT-related fields, such as microbiological water quality tests, micro pollutant identification, and even device-specific adjustments in WWTP management, is the combination of sensitive fluorescence measurements with very specific Raman measurements enhanced with AI (Bhagat et al., 2020; Wang et al., 2023b).

PROCESS OPTIMIZATION

Process parameter optimization's primary goals are to save expenses and boost WWT efficiency. This used mesoporous rGO/Fe/Co Nano hybrids and RSM, ANN-PSO, and ANN-GA models to investigate the decontamination of methylene blue (MB) from simulated wastewater. The outcomes demonstrate that, out of all of these models, the ANN-PSO model performs the best in terms of predicting the ideal circumstances for decontamination efficiency. The use of mesoporous Nano hybrids as a quick and inexpensive decontaminant material for organic contaminants or other pollutants in wastewater could be explored (Wang et al., 2023a). The chemical makeup of pollutants can be examined using FTIR spectra, which can also be used to identify functional groups (N. K. Singh et al., 2023). These spectra can provide valuable information on functional groups that are present in compounds, complex substances, and bio-

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sorbent surfaces, but interpreting them takes time (Nourani et al., 2018). The first generalizable model based on CNN to detect functional groups in gas-phase FTIR spectra was created in order to shorten the time required to analyze functional groups and facilitate the understanding of FTIR spectra (Martini & Roni, 2021). The findings show that CNN models can be used to various micro pollutants or chemical identification application domains with a large number of spectral examples and are effective at recognizing spectral features. In general, spectroscopy methods like FTIR, SEM, and Raman spectroscopy in conjunction with image-based AI models are helpful for the identification and detection of pollutants (Jawad, Hawari, & Zaidi, 2021).

CURRENT STUDY

Due to the increase in contaminated water that come from industries, houses, and other places there is need to treat this wastewater at very rapid rate. For this purpose scientists are working on the bioreactors to make them more efficient to treat this wastewater. Wastewater treatment using bioreactors involves the use of microorganisms to break down organic pollutants. Common types include activated sludge and fixed-film bioreactors (Jou & Huang, 2003). Microorganisms in the bioreactor consume pollutants, promoting water purification. Advances in this field focus on optimizing microbial communities, enhancing nutrient removal, and exploring sustainable energy production from the process. Continuous research seeks improved bioreactor designs, efficient microbial consortia, and eco-friendly methods to address emerging contaminants, contributing to more effective and sustainable wastewater treatment. In artificial intelligence, researchers are working on various aspects which includes advances algorithms for predictive analytics and real time monitoring of water quality (Martini & Roni, 2021).

FUTURE PROSPECTS

Ongoing research aims to enhance efficiency, reduce costs, and address emerging contaminants, advancing the field of wastewater treatment using bioreactors. Moreover, continued advancements in sensor technologies, automation, and artificial intelligence will enhance the monitoring and control of bioreactor systems, optimizing their performance for various wastewater compositions. Moreover, artificial intelligence will be more advanced as compared to present and it will increase the speed as well more efficiency of treatment process for wastewater.

CONCLUSION

In conclusion, the applications of bioreactors in wastewater treatment underscore their versatility and effectiveness in addressing environmental challenges. Whether through activated sludge systems, sequencing batch reactors, anaerobic digesters, or innovative designs like moving bed biofilm reactors, bioreactors play a pivotal role in harnessing the power of microorganisms to degrade and remove pollutants from wastewater. Their ability to adapt to varying influent characteristics, handle different types of pollutants, and promote sustainable practices makes them integral components of modern wastewater treatment plants. From industrial facilities to municipal treatment systems, bioreactors contribute to the purification of water resources, reducing environmental impact, and ensuring compliance with water quality standards.

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