The Bioscan
AN INTERNATIONAL QUARTERLY JOURNAL OF LIFE SCIENCES
21(1), 620-627, 2026 www.thebioscan.com

A Review on Redefining Industrial Effluent Treatment for A Sustainable Future

Tejashree V, Sheela Rani T*, Abitha P S, Mahesh Kumar S, Deepikaa S K

[1]Sri Ramachandra Faculty of Pharmacy, Sri Ramachandra Institute of Higher Education and Research (DU), Chennai, India – 600 116.

***Corresponding Author: Sheelarani T,** sheelarani.t@sriramachandra.edu.in

DOI: https://doi.org/10.63001/tbs.2026.v21.i03.pp620-627

KEYWORDS
Wastewater, treatment, pollution, Environmental Regulations, Water Reuse, Sustainable Development

Received on: 02/07/2026

Revised on: 16/07/2026

Accepted on: 23/07/2026

Published on: 31/07/2026

Abstract

Accelerated urbanization and rapid industrial expansion have led to a substantial increase in wastewater generation, posing significant challenges to environmental sustainability and the conservation of freshwater resources. Effluent Treatment Plants (ETPs) play a critical role in industrial pollution control by treating contaminated wastewater prior to its discharge or reuse. This review, with particular emphasis on the pharmaceutical industry, highlights the importance of ETPs in protecting aquatic ecosystems, safeguarding public health, and ensuring adherence to environmental regulations. The article outlines the major characteristics and sources of industrial wastewater, key treatment parameters, and the classification of treatment facilities, including ETPs, Sewage Treatment Plants (STPs), and Common Effluent Treatment Plants (CETPs). It further provides a systematic discussion of the sequential stages of wastewater treatment like preliminary, primary, secondary, and tertiary -incorporating conventional physical, chemical, and biological treatment processes. In addition, recent advancements in wastewater treatment are examined, focusing on emerging technologies such as Moving Bed Biofilm Reactors (MBBR), Membrane Bioreactors (MBR), Sequencing Batch Reactors (SBR), and advanced oxidation processes. The review also emphasizes the importance of regulatory standards, discharge limits, and effective operational practices in achieving environmental compliance. Overall, the implementation of efficient effluent treatment systems is essential for minimizing pollution, conserving water resources, supporting sustainable industrial development, and ensuring long-term environmental protection.

1. INTRODUCTION

Water is one of the most vital natural resources for all life on Earth. It is crucial to nature because it nourishes all life, influences the planet's temperature and landscapes, and promotes biodiversity. Plants, animals, and people rely on it for drinking, growth, and metabolic activities. Water's unique solvent characteristics, involvement in the water cycle, and ability to regulate temperature are critical for supporting ecosystems and geological processes. As for life, Water supports vital processes like metabolism, nutrient transport, and temperature regulation. It also fosters diverse ecosystems in aquatic environments and is crucial for plant growth through photosynthesis. Furthermore, water regulates the environment by moderating temperature, shaping landscapes, and transporting nutrients. In human activities, water is indispensable for agriculture, industry, sanitation, and recreation, underpinning food security and economic development.[1,2,3]

It is a universal solvent necessary for life-sustaining chemical reactions and allows sunlight penetration for aquatic plants. Total utilizable water resource in the country has been estimated to be about 1123 BCM (690 BCM from surface and 433 BCM from ground), which is just 28% of the water derived from precipitation. Figure 1 represents a detailed pie chart of land-use distribution across different sectors. Urban residential areas occupy the largest proportion, indicating extensive housing development. Commercial and agricultural lands also contribute significantly. Smaller shares are taken by industrial zones, large landscapes, energy production areas, and wetlands, showing limited allocation to natural and utility-based land uses.

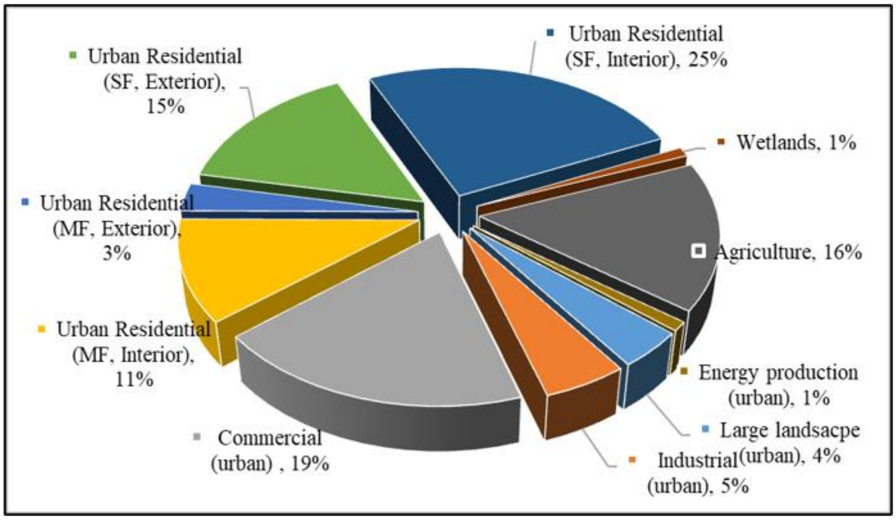

Figure 1: Overview of wastewater generation across major sections

Wastewater is the used water from households, businesses, industries, agriculture, or stormwater runoff that has become contaminated and unsuitable for direct reuse. This includes excess liquids from domestic tasks like drinking and cleaning, runoff from urban rainfall that contains pollutants like metals and oils, hazardous materials found in highway drainage, and industrial waste from site drainage and illicit disposal.[4,5,6]

The release of pollutants into surface waters has been further exacerbated by the disposal of organic and inorganic waste as well as active chemicals from different businesses. Pharmaceutical effluents are the residual by-products that are released by the pharmaceutical industries during the production processes. It contains high level of pollutants, organic matter that is not biodegradable, including detergents, personal care products, animal and plant steroids, reproductive hormones, lipid regulators, anti-inflammatories, analgesics, antibiotics, and other prescription and over-the-counter medications. The effluents must be treated to prevent the pollution of the receiving water or may be reused or released to a sanitary sewer or to a surface water in the environment. Most industries generate some wastewater, but in the developed world, recent trends have been to either reduce or recycle this wastewater during the production process. Nonetheless, a lot of industries still rely on wastewater-producing processes.

It includes - Effluent treatment plants (ETP), Sewage treatment plants (STP) and Common and combined effluent treatment plants (CETP)

The purpose of the effluent water treatment plants is to lessen the likelihood of contamination especially the amounts of biodegradable organics that remain undissolved throughout the purification process and the potential for water pollution. ETPs can be set up in industries such as chemicals, pharmaceuticals, leather goods, and tanneries.[7,8,9]

STPs are essential for managing urban wastewater safely, preventing water pollution and disease outbreaks in order to protect public health and the environment by reducing pollutants such as organic matter, pathogens, nutrients, and suspended solids. They support water recycling efforts in water-scarce areas and protect aquatic ecosystems. Properly functioning STPs also reduce odours and minimize solid waste disposal issues by converting sludge into biogas or fertilizer through digestion processes.[10,11,12]

CETPs include collection and equalization tanks to store and homogenize wastewater streams from various industries to maintain stable pH and pollutant levels. The primary treatment process involves screening, grit removal, and sedimentation, utilizing chemical coagulants to eliminate solids. Biological treatment follows, employing microbes for organic matter decomposition in aerobic or anaerobic settings. Then, secondary biological treatment takes place in aeration tanks or reactors, with further tertiary processes for filtration, nutrient removal, and disinfection. The treated effluent is either safely discharged or reused, while sludge is processed for disposal or biogas production.[13,14,15]

An estimated 1.8 million individuals pass away from waterborne illnesses each year. Inadequate sanitation practices are indirectly responsible for a significant portion of these fatalities. For the benefit of society and our future, wastewater treatment is a crucial project that has to be given more careful consideration. Wastewater treatment is the process of removing pollutants from both home and wastewater sewage to create a waste stream or solid waste that is ready for disposal or reuse.

2. EFFLUENT TREATMENT PLANT

ETPs are used in the pharmaceutical to eliminate any toxic and non-toxic or chemicals and also to purify the water to lower the price of buying water. These plants are mostly used by all type of manufacturing companies for the protection of environment like in some of the industrial sector such as Textile industry, Pharmaceutical industry, Chemical manufacturing, Pulp and paper industry, Tannery and leather industry, Food and beverage processing, Sugar industry, Dairy industry, Oil and petroleum refining, Electroplating and metal finishing, Fertilizer industry, Distillery and brewery industry to remove the effluents from the bulk substances. It ensures that the contaminated and polluted water from the industries is managed and become safe, reliable and reusable, before it is being released to the nature.

2.1 Parameters of ETP

As different companies have different composition of wastewater, they require different effluent treatment plant. Therefore, a basic ETP depends on the following parameters:

2.1.1 Physical parameter: For evaluating water quality both before and after treatment, physical characteristics of wastewater such as pH, temperature, turbidity, total suspended solids (TSS), total dissolved solids (TDS), colour, odor, and conductivity are essential. Temperature influences oxygen levels and microbial activity, whereas pH indicates acidity or alkalinity. TDS stands for dissolved salts, while turbidity and TSS show suspended particles. Odor and colour could indicate decomposition or contamination. For primary treatment procedures like screening, sedimentation, and equalization to be successful, these parameters must be monitored.

2.1.2 Chemical parameter: Chemical parameters have an impact on treatment process design and are essential in determining wastewater pollution levels. BOD, COD, TOC, nutrients (phosphorus and nitrogen), oil and grease, chlorides, sulphates, heavy metals, phenols, and cyanides are important indicators. While TOC gauges total organic content, BOD and COD show organic load and oxygen requirements. Oil and grease interfere with microbial processes, and nutrients lead to eutrophication. Toxic materials and heavy metals require specialized techniques. To protect aquatic ecosystems and comply with pollution regulations, its crucial.

2.1.3 Biological parameter: In secondary treatment systems, like activated sludge, biological parameters are essential for evaluating microbial activity and health. Mixed liquor suspended solids (MLSS) and mixed liquor volatile suspended solids (MLVSS) for microbial biomass, total and faecal coliforms for harmful microorganisms, and the sludge volume index (SVI) for sludge settling characteristics are important indicators. Keep an eye on these variables aids in preserving ideal circumstances for the breakdown of organic pollutants. E.g. Bacteria, Viruses, and protozoa's which are harmful to environment and also leads to dangerous side effects.

2.2 Levels in treating the waste water:

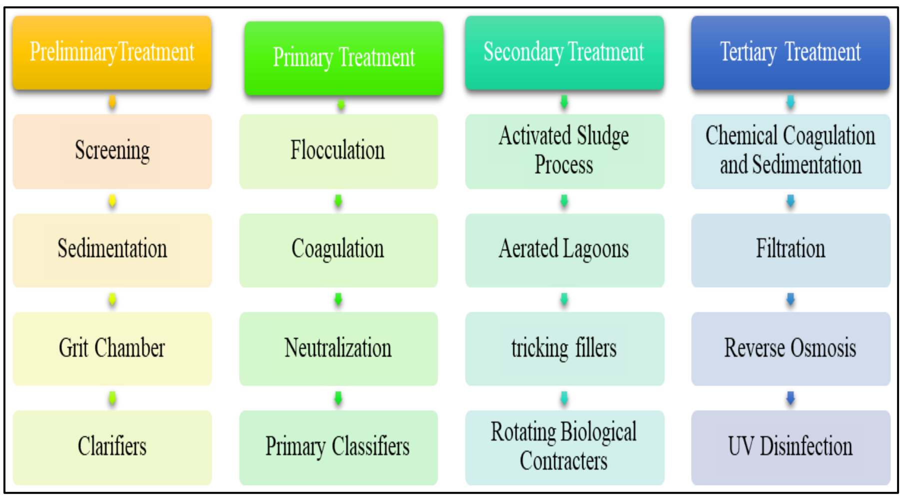

Figure 2: Stages of effluent treatment plant in pharmaceutical industry

Figure 2 illustrates the stepwise process of wastewater treatment. It begins with preliminary treatment, where large solids and grit are removed.[16,17,18]

2.2.1 Preliminary level: This stage is the first screening, with the objective of physically separating large contaminants such as paper, cloth, plastics, wood logs, etc.

2.2.2 Screening: It is the first stage of processing in a waste water treatment facility. The purpose of a screen with regular openings is to eliminate large floating solids.

2.2.3 Sedimentation: It is the practical treatment way that uses the gravity for eliminating the suspended materials from water.

2.2.4 Grit Chamber: Sand, gravel, and other thick inorganic elements that have found their way into the sewers are removed by the wastewater that passes through the grit chamber. Eliminating grit can help shield pumps from harm and operational issues.

2.2.5 Clarifiers: Clarifiers are mechanically operated tanks designed to continually remove sediments that have been deposited by sedimentation before biological treatment.

2.2.6 Primary level: Primary Treatment Level focuses on removing suspended solids and organic matter from wastewater using physical and chemical methods.

2.2.7 Flocculation: There is no neutralization of charges involved in this physical process. To make them easier to remove from the water, it involves aggregating destabilized particles into large aggregates.

2.2.8 Coagulation: This process involves adding coagulants to a liquid in order to hasten the settlement of tiny solid particles into a larger bulk. It enables the removal of particles by filtering and sedimentation.

2.2.9 Neutralization: The major aim of this step is to maintain pH of the water between 6 and 9 to facilitate the need of various processing unit in the ETP system.

2.2.10 Primary Classifiers: These have equipment for removing greases and floating solids from the surface as well as a function that lowers the water's velocity to the point when organic items sink to the bottom of the tank.

2.3 Secondary level or biological treatment: At the secondary level of treatment, biodegradable organic waste materials are removed through a series of biological and chemical processes.

2.3.1Activated Sludge Process: This technique cleans industrial waste water by using air and a biological floc composed of microorganisms.

2.3.2 Aerated Lagoons: It is an artificially aerated processing pond to boost the biological oxidation of waste water.

2.3.3 Trickling Filters: It is extensively used for the biological treatment of home and industrial waste water which is also known as sprinkling filters.

2.3.4 Rotating Biological Contactor: In order to eliminate contaminants from wastewater before releasing the treated wastewater into the environment, this approach involves letting the wastewater come into contact with a biological medium.

2.4 Tertiary level: By eliminating dangerous microorganisms and inorganic compounds, the final cleaning procedure enhances the quality of wastewater prior to reuse or discharge. It includes:

2.4.1 Chemical Coagulation and sedimentation: This method is applied after primary and secondary treatment to enhance the removal of particles from effluent.

2.4.2 Filtration: The cleaned wastewater is initially sent through a nearby filtration plant with large filter blocks to ensure high-quality water.

2.4.3 Reverse Osmosis: Using this technique, wastewater is forced through a membrane that lets clean water through on one side while trapping pollutants on the other.

2.4.4 UV Disinfection: Industrial waste water is a suitable use for this kind of disinfection. It ensures that there is no residual disinfectant in the water by keeping it pure. Disinfection by products is not generated. 19,20,21tablet.

3. CHARACTERISTICS OF PHARMACEUTICAL WASTE WATER:

Typical features of high-strength industrial effluent are shown in the Table1
It's extremely high BOD and COD levels suggest a significant organic load. High amounts of phosphorus and nitrogen indicate a high risk of nutrient pollution 22,23,24 High turbidity and colour are also reflected by suspended solids and chromaticity, which are important. Significant differences in pH and temperature suggest varying process conditions, necessitating strong treatment techniques and efficient equalization prior to safe reuse or discharge.

Table 1: Baseline Characteristics of Industrial Wastewater

COD (mg/L)	Bod (mg/L)	Total Nitrogen (mg/L)	Total Phosphorus (mg/L)	Suspended Solids (mg/L)	Chromaticity (times) (mg/L)	Temperature (°C)	pH
1000-10000	500-2500	500- 1500	50- 250	200- 500	500- 1000	25- 80	1-08

3. MODERN AND ADVANCED WASTE WATER TREATMENT IN PHARMACEUTICAL INDUSTRY:

4.1 Moving Bed Biofilm Reactor:

When the organic matter content of the waste water is high and biological treatment is appropriate, MBBR is without a doubt the most effective option. The foundation of this method is the development of biomass as a biofilm on plastic supports, High Density Polyethylene (HDPE) carrier elements, that are continuously moving within or fixed to the biological reactor and the growth has been proposed. In the latter case where the carrier element is moving, the process is Moving Bed Biofilm Reactor (MBBR). These types of systems are referred to as Integrated Fixed-film Activated Sludge process (IFAS). Compared to conventional reactors, these supports allow more biomass to flow per unit of volume because they have a greater specific surface area per unit of volume. It is an effective method of removing high levels of BOD, COD and ammonia (nitrification/ de-nitrification). MBBR can also integrate with wastewater treatment plants for various applications. 25

4.2 Membrane Bioreactor:

This method involves the combination of both biological treatment and membrane filtration for the high efficiency removal of BOD, COD and suspended solid particles compared to the conventional biological treatment. The waste water is first treated with the bioreactor where the microorganisms break down the organic pollutants and it is passed through a microfiltration or ultrafiltration membrane. The membrane module is often suspended in the bioreactor like that of activated sludge method. Microfiltration and ultrafiltration are the common methods of filtration in waste water treatment. This process removes the suspended solid particles, other bacteria, and contaminants, which results in the high-quality effluent. 26

4.3 Sequencing Batch Reactor:

SBR is one of the aerobic treatment technologies to treat waste water in a single tank where the waste is removed in a specific sequence. This process operates in a five cycle steps – filling, reacting, settling, decanting, and idling. The waste water (influent) is filled in a tank and it is made to react with the oxygen by providing aeration, aerobic bacteria convert the organic matter by breaking down into ammonia and to nitrate (nitrification). Activated sludge settles at the bottom when the aeration is stopped, and separate carefully the supernatant water by decantation. Idle period is the time gap before the next cycle begins and tank is prepared for the next fill. SBR is one of the flexible methods for handling the fluctuation in influent loads. It effectively removes the organic matters, nitrogen and phosphorous. 27

4.4 Advanced Oxidation Process:

More sophisticated methods of pollutant removal are needed when the concentration of hazardous or persistent compounds in waste water is high, or when the contaminants have a low capacity to decompose. Advanced oxidation is a broad term that includes many different techniques, most of which depend on producing hydroxyl radicals or providing the energy needed to break down the polluting molecule. These techniques work especially well for getting rid of dyes, detergents, and halogenated hydrocarbons (benzene, toluene, phenol, and other similar substances). Fenton's reagent, anodic oxidation, electro-chemical oxidation, catalytic ozonation, photo catalysis, and the reaction of hydrogen peroxide with UV radiation are the most often used methods among the several techniques that are accessible.

4.5 Nanotechnology based treatments:

Nanofiltration is a membrane process that is widely used in water treatments for both drinking water and waste water. This method separates materials in the 0.001-0.1 micrometre size by a low-pressure membrane process. Nanofiltration membranes are pressure-driven membranes having pore size between 0.2 and 4 nm with properties between those of reverse osmosis and ultra filtration. They are used for softening the hardwater, for removing dissolved organic matter and trace pollutants from surface water, pretreatment in seawater desalination, removal of turbidity, microorganisms and inorganic ions such as Ca and Na. 28

4.6 Electrocoagulation and electro oxidation:

Electrocoagulation uses electric current to release metal ions (Al or Fe) that form hydroxide flocs, which trap and remove suspended solids and heavy metals. Electrooxidation generates strong oxidizing agents at the electrode surface that degrade organic pollutants. The combined process effectively reduces COD, BOD, turbidity, and color.29

4.7 Forward osmosis (FO) & Pressure retarded osmosis (PRO):

These are emerging membrane separation methods that use a semipermeable membrane to separate the dissolved solutes from water. They rely on osmotically driven water flux across the semipermeable membrane. In PRO the high concentration solution draws the water from low concentration which creates a pressure. This pressure is then further used to drive hydro turbine to generate electricity.

4.8 Enzymatic treatments:

Specific enzymes like laccases, peroxidases, lipases are used for the biodegradation of micropollutants including pharmaceuticals, steroid hormones, personal care products, pesticides, and industrial dyes. The enzymes breakdown complex, recalcitrant organic pollutants into simple and degradable form thereby reducing the BOD/COD in water. Enzymes act as the powerful catalysts during this breakdown. Other technologies like Advanced Oxidation Processes (AOD) and Membrane Reactors (MBR's) are also integrated with this method for more efficient treatment for complex pharma waste water. 30

4.9 Activated Sludge process:

It is not the most recommended method because of the potential for harmful and inhibitory compounds for the biomass and the low biodegradability of some of the generated effluents, even if this is the most competitive process for waste water with easily biodegradable organic matter. If the toxins are biodegradable, however, the technique is simple and effective.

4.10 Vacuum evaporators with mechanical steam compression:

Used when biological treatment is unsuitable, this process removes water by evaporation under vacuum conditions. Mechanical steam compression improves energy efficiency, making it suitable for high-strength industrial effluents. This produces superheated steam, which uses up its energy in a heat exchanger to heat the water that will evaporate as the steam condenses. When operating in vacuum, the boiling point and steam temperature range from 60ºC to 90ºC.

4.11 Smart and AI-enabled ETP systems:

For real-time monitoring and process optimization, contemporary wastewater treatment plants are increasingly utilizing digital platforms. Operators can maximize performance, minimize downtime, and guarantee compliance with the use of cloud-based dashboards, AI-driven analytics, and predictive maintenance solutions. Predictive maintenance is also made easier by digitization, which reduces operating disturbances and enables early detection of possible problems. Use of IoT sensors tracks the parameters like pH, flow rate, BOD, COD concentration of the pollutants. Based on this real time analysis of data, the AI adjusts the operational process to optimize treatment efficiently and reduce cost.

5. EFFLUENT GUIDELINES IN THE PHARMACEUTICAL MANUFACTURING INDUSTRY

The Central Pollution Control Board (CPCB) in India has specific regulations and guidelines regarding the discharge of pharmaceutical effluents to prevent water pollution and protect the environment. The regulatory framework and guidelines pertaining to pharmaceutical effluent from the CPCB:

5.1 Effluent Standards: The CPCB sets effluent discharge standards for various industries, including pharmaceutical manufacturing units. These standards specify the maximum permissible concentrations of various pollutants in the effluent discharged from pharmaceutical plants. Parameters such as biochemical oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), pH, and specific toxic substances are regulated.

5.2 Consent to Establish and Operate: Pharmaceutical manufacturing units are required to obtain consent to establish and operate from the respective State Pollution Control Boards (SPCBs) or Pollution Control Committees (PCCs). This consent outlines conditions and standards that must be met to prevent pollution and protect the environment, including effluent discharge limits and monitoring requirements.

5.3. Monitoring and Reporting: Pharmaceutical units are required to monitor the quality of their effluent discharge regularly and submit monitoring reports to the respective pollution control authorities. Monitoring parameters typically include those outlined in the effluent standards set by the CPCB and may vary based on the type of pharmaceutical processes and pollutants generated.

5.4. Environmental Management Plans: Pharmaceutical units are encouraged to develop and implement Environmental Management Plans (EMPs) to minimize the environmental impact of their operations, including effluent generation and discharge. EMPs may include measures such as pollution prevention, water conservation, and the use of advanced treatment technologies to reduce the environmental footprint of pharmaceutical manufacturing processes.

5.5. Zero Liquid Discharge (ZLD): The CPCB promotes the adoption of Zero Liquid Discharge (ZLD) technologies in pharmaceutical units to minimize water consumption and eliminate effluent discharge. ZLD systems treat and recycle wastewater generated during pharmaceutical manufacturing processes, thereby reducing the volume of effluent discharged and conserving water resources.

5.6. Environmental Audits and Inspections: The CPCB conducts environmental audits and inspections of pharmaceutical manufacturing units to assess compliance with effluent standards and regulatory requirements. Non-compliance may result in penalties, fines, or other enforcement actions to ensure adherence to regulations.

5.7. Public Awareness and Stakeholder Engagement: The CPCB engages in public awareness campaigns and stakeholder consultations to educate pharmaceutical industries, workers, and communities about the importance of environmental protection and pollution prevention measures. Public participation is encouraged in the formulation of policies and regulations related to pharmaceutical effluent management.

By complying with CPCB regulations and guidelines, pharmaceutical manufacturing units can mitigate the environmental impact of their operations and contribute to sustainable development and environmental protection efforts in India.

5s checklist for effluent treatment plant:

Table 2: Daily Operational and Safety Inspection Checklist for ETP/MEE

S.No.	point of observation	Yes	No	Remarks
01.	Check the ETP/ MEE any pumps & pipelines leakages.			
02.	Check all the motors guards & coupling guards available.			
03.	Check any abnormal sound of pumps and motors			
04.	Check all the level of indicators are clear visibility			
05.	Check the MEE plant all the automatic indicators are working.			
06.	Check the abnormal sounds/vibrations observed in MEE & ATFD			
07.	All the ETP/ MEE area housekeeping is good?			
08.	Check H.W stocks limit not exceeded in storage area.			
09.	Check the PIIAN spraying is working and in running.			
10.	Check all the effluent parameters are in as per limit/ standard.			
11.	Check the drums stock in ETP area. (If available, remove immediately.)			
12.	Ensure any odour nuisance in ETP area.			
13.	Check the painting for pipe line is required?			

Table 2 represents a checklist for routine inspections of multiple effect evaporators and effluent treatment operations. It sets a strong emphasis on equipment condition, housekeeping, safety measures, and environmental compliance. Important observations include looking at motors, pumps, pipelines, indications, noise, vibrations, and chemical storage. In addition, proper material handling, effluent quality, and odor control are taken into account. Routine monitoring with this checklist ensures that the treatment system functions safely, legally, and efficiently.

Acceptance level of contaminants:

Table 3: EPA Discharge Standards for Treated Effluent Quality

S. No.	Parameter	EPA Standard
01.	Temperature (°C)	<30
02.	pH	6- 9
03.	TSS (mg/l)	50
04.	TP (mg/l)	2
05.	Turbidity (NTU)	75
06.	TN (mg/l)	50
07.	Ammonia/ Ammonium (mg/l)	1
08.	BODs (mg/l)	50
09.	COD	250
10.	Conductivity (μs/cm)	750

11.	TDS (mg/l)	1500
12.	DO	1
13.	TC (MPN/100ml)	400
14.	E.coli (MPN/100ml)	10

6. SIGNIFICANCE OF EFFLUENT TREATMENT

By eliminating dangerous contaminants from wastewater prior to discharge, effluent treatment facilities are essential to environmental protection. They support sustainable industrial and ecological balance by lowering health risks, preventing soil and water contamination, ensuring industries adhere to environmental regulations, and assisting in water conservation through reuse. 31,32 Some of them are discussed as follows:

6.1 Adherence to Environmental Regulations: The pharmaceutical sector generates diverse effluent streams that may harbour hazardous substances, solvents, and pharmaceutical remnants. In order to ensure compliance with local, state, and federal environmental laws, ETPs are designed to remove these toxins.

6.2 Protection of Public Health: Drugs may have negative impacts on both the environment and human health. By aiding in their breakdown, these substances are kept out of natural water bodies where they could endanger aquatic life and possibly have an impact on drinking water supplies downstream.

6.3 Corporate Social Responsibility: A lot of pharmaceutical companies emphasize their dedication to CSR and environmental sustainability. Maintaining a functional ETP demonstrates a dedication to reducing the environmental impact of the sector and handling trash in an ethical manner.

6.4 Cost Savings: Pharmaceutical businesses can recover energy and water from wastewater, which are significant resources, by using efficient ETPs. Businesses can cut expenses and support sustainability initiatives by reusing treated water and capturing energy.

6.5 Legal Compliance and Obligations: Pharmaceutical businesses may face fines, penalties, or even legal action if they violate environmental standards. By ensuring that wastewater is handled in accordance with legal regulations, an ETP helps businesses avoid these penalties.

6.6 Process Optimization: ETPs can also help with process optimization in the production of pharmaceuticals. Businesses can find areas where process modifications can lower pollution generation and increase operational efficiency by assessing and treating wastewater.

6.7 Risk Mitigation: The uncontrolled discharge of pharmaceutical residues may give rise to possible hazards, such as the emergence of drug-resistant bacteria within the surroundings. By eliminating or neutralizing these chemicals prior to discharge, ETPs reduce these dangers.

7. CONCLUSION

Effluent Treatment Plants (ETPs) are indispensable for controlling industrial pollution and ensuring sustainable wastewater management, particularly in the pharmaceutical sector where effluents are often complex and high in organic and chemical load. Effective treatment through preliminary, primary, secondary, and tertiary processes—supported by advanced technologies such as MBBR, MBR, SBR, and advanced oxidation processes—significantly reduces environmental and public health risks. Compliance with regulatory standards and continuous monitoring further enhance operational efficiency and environmental protection. The integration of modern treatment approaches, resource recovery strategies, and smart monitoring systems can strengthen pollution control efforts while promoting water conservation and sustainable industrial development. Overall, well-designed and properly managed ETP systems are vital for long-term ecological balance and responsible industrial growth.

Acknowledgement- Authors of this article acknowledge their gratitude to Sri Ramachandra Institute of Higher Education and Research (DU), Porur, Chennai for their support and encouragement.

Conflicts of Interest - The authors declare that they have no conflicts of interest.

Funding- Self Fund

Abbreviations:

AOP – Advanced Oxidation Process

APHA – American Public Health Association

BOD – Biochemical Oxygen Demand

CETP – Common Effluent Treatment Plant

COD – Chemical Oxygen Demand

CPCB – Central Pollution Control Board

DO – Dissolved Oxygen

EPA – Environmental Protection Agency

ETP – Effluent Treatment Plant

FO – Forward Osmosis

HDPE – High-Density Polyethylene

MBR – Membrane Bioreactor

MBBR – Moving Bed Biofilm Reactor

MEE – Multiple Effect Evaporator

MLSS – Mixed Liquor Suspended Solids

MLVSS – Mixed Liquor Volatile Suspended Solids

PRO – Pressure Retarded Osmosis

SBR – Sequencing Batch Reactor

STP – Sewage Treatment Plant

TDS – Total Dissolved Solids

TN – Total Nitrogen

TOC – Total Organic Carbon

TP – Total Phosphorus

TSS – Total Suspended Solids

ZLD – Zero Liquid Discharge

6. REFERENCES=

- Asiwal RS, Sar SK, Singh S, Sahu M. Wastewater treatment by effluent treatment plants. SSRG Int J Civ Eng. 2016;3(12):1–6.
- Chitnis V, Chitnis S, Vaidya K, Ravikant S, Patil S, Chitnis DS. Bacterial population changes in hospital effluent treatment plant in central India. Water Res. 2004;38:441–447.
- Ghumra DP, Agarkoti C, Gogate PR. Improvements in effluent treatment technologies in Common Effluent Treatment Plants (CETPs): Review and recent advances. Process Saf Environ Prot. 2021;147:1018–1051.
- Bhutiani R, Pratap H, Ahamad F, Kumar P, Kaushik PD. Efficiency assessment of effluent treatment plant (ETP) treating an automobile industry effluent (Sidcul) Haridwar. Environ Conserv J. 2017;18(1–2):95–102.
- Singh A, Sawant M, Kamble SJ, Herlekar M, Starkl M, Aymerich E, Kazmi A. Performance evaluation of a decentralized wastewater treatment system in India. Environ Sci Pollut Res. 2019;26(21):21172–21188.
- Boyd CE. Guidelines for aquaculture effluent management at the farm-level. Aquaculture. 2003;226(1–4):101–112.
- Mao G, Han Y, Liu X, Crittenden J, Huang N, Ahmad UM. Technology status and trends of industrial wastewater treatment: A patent analysis. Chemosphere. 2022;288:132483.
- Qiqi Y, Ibrahim HT, Qiang H. Review on moving bed biofilm processes: Improvements in biofilm processes for wastewater treatment. J Environ Sci. 2012;24(11):708–734.
- Gogate PR, Pandit AB. A review of imperative technologies for wastewater treatment I: Oxidation technologies at ambient conditions. Adv Environ Res. 2004;8(3–4):501–551.
- Irvine RL, Busch AW. Sequencing batch biological reactor: An overview. J Water Pollut Control Fed. 1979;51:235–243.
- Bhattacharya S, Saha I, Mukhopadhyay A, Chattopadhyay D, Ghosh UC, Chatterjee D. Role of nanotechnology in water treatment and purification: Potential applications and implications. Int J Chem Sci Technol. 2013;3(3):59–64.
- Linares-Hernández I, Barrera-Díaz C, Bilyeu B, Juárez-García Rojas P, Campos-Medina E. A combined electrocoagulation-electrooxidation treatment for industrial wastewater. J Hazard Mater. 2010;175(1–3):688–694.
- Elsheikh MA, Al-Hemaidi WK. Approach in choosing suitable technology for industrial wastewater treatment. J Civ Environ Eng. 2012;2(5).
- Hegazy MH, Gawad MA. Measuring and evaluating the performance of a wastewater treatment plant. In: Proc World Congr Civ Struct Environ Eng. 2016; Paper No. AWSPT.
- Shete BS, Shinkar NP. Dairy industry wastewater sources, characteristics & its effects on environment. Int J Curr Eng Technol. 2013;3(5):1611–1615.
- Punmia BC, Jain AK, Jain AK. Wastewater engineering. New Delhi: Firewall Media; 1998.
- Padalkar AV, Kumar R. Common effluent treatment plant (CETP): Reliability analysis and performance evaluation. Water Sci Eng. 2018;11(4):315–325.
- Kulkarni SJ, Goswami AK. A review on wastewater treatment for petroleum industries and refineries. Int J Innov Res Sci Eng Technol. 2015;1:280–283.
- Ahmed MB, Zhou JL, Ngo HH, Guo W, Thomaidis NS, Xu J. Progress in the biological and chemical treatment technologies for emerging contaminant removal from wastewater: A critical review. J Hazard Mater. 2017;323:274–298.
- Luo Y, Guo W, Ngo HH, Nghiem LD, Hai FI, Zhang J, Liang S, Wang XC. A review on the occurrence of micropollutants in the aquatic environment and their fate and removal during wastewater treatment. Sci Total Environ. 2014;473–474:619–641.
- Rivera-Utrilla J, Sánchez-Polo M, Ferro-García MÁ, Prados-Joya G, Ocampo-Pérez R. Pharmaceuticals as emerging contaminants and their removal from water: A review. Chemosphere. 2013;93(7):1268–1287.
- Zhang Y, Geißen SU, Gal C. Carbamazepine and diclofenac: Removal in wastewater treatment plants and occurrence in water bodies. Chemosphere. 2008;73(8):1151–1161.
- Yang Y, Ok YS, Kim KH, Kwon EE, Tsang YF. Occurrences and removal of pharmaceuticals and personal care products (PPCPs) in drinking water and water/sewage treatment plants: A review. Sci Total Environ. 2017;596–597:303–320.
- Tiwari B, Sellamuthu B, Ouarda Y, Drogui P, Tyagi RD, Buelna G. Review on fate and mechanism of removal of pharmaceutical pollutants from wastewater using biological approach. Bioresour Technol. 2017;224:1–12.
- Homem V, Santos L. Degradation and removal methods of antibiotics from aqueous matrices – A review. J Environ Manage. 2011;92(10):2304–2347.
- Tran NH, Reinhard M, Gin KYH. Occurrence and fate of emerging contaminants in municipal wastewater treatment plants from different geographical regions: A review. Water Res. 2018;133:182–207.
- Verlicchi P, Al Aukidy M, Zambello E. Occurrence of pharmaceutical compounds in urban wastewater: Removal, mass load and environmental risk after secondary treatment. Sci Total Environ. 2012;429:123–155.
- Metcalf & Eddy Inc, Tchobanoglous G, Stensel HD, Tsuchihashi R, Burton F. Wastewater engineering: Treatment and resource recovery. 5th ed. New York: McGraw-Hill Education; 2014.
- Spellman FR. Handbook of water and wastewater treatment plant operations. 4th ed. Boca Raton: CRC Press; 2021.
- Rittmann BE, McCarty PL. Environmental biotechnology: Principles and applications. 2nd ed. New York: McGraw-Hill; 2001.
- Rajeshwari KV, Balakrishnan M, Kansal A, Lata K, Kishore VVN. State-of-the-art of anaerobic digestion technology for industrial wastewater treatment. Renew Sustain Energy Rev. 2000;4(2):135–156.
- Fatta-Kassinos D, Meric S, Nikolaou A. Pharmaceutical residues in environmental waters and wastewater: Current state of knowledge and future research. Anal Bioanal Chem. 2011;399:251–275.
- British Pharmacopoeia. Sitagliptin phosphate monograph. London: MHRA; 2024.
- Lakshmana Prabu S, Suriyaprakash TNK. Cleaning validation and its importance in pharmaceutical industry. Pharma Times. 2010;42(7):21-25.
- Sandle T. Cleaning validation: an overview of principles and best practices. Eur J Parenter Pharm Sci. 2013;18(3):65-72.
- WHO. Supplementary guidelines on GMP: Validation. WHO Technical Report Series 937, Annex 4; 2006.
- Mahajan V, Dixit A, Bhargava S. Cleaning validation in pharmaceutical industry: a review. Int J Pharm Sci Res. 2014;5(11):4568-4578.