

Pharmaceutical Industry Analysis and Wastewater Treatment Technologies

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Abstract

The research assesses the effectiveness of a wastewater treatment facility serving pharmaceutical industrial hubs in Aurangabad, Maharashtra, with a daily treatment capacity of 150 cubic meters. This facility utilizes a multi-stage process, combining physical, chemical, and biological methods to treat complex wastewater from manufacturing, laboratory, and support operations. Over 18 sampling periods, wastewater samples were taken from the facility's inlet and outlet and examined for various key parameters, including acidity levels, chemical oxygen demand, biological oxygen demand, total dissolved and suspended solids, chloride, sulfate, and oil and grease content. The findings show significant reductions in pollutant levels, with chemical oxygen demand dropping from 840-8560 milligrams per liter to 140-240 milligrams per liter, and biological oxygen demand decreasing from 228-2380 milligrams per liter to 30-92 milligrams per liter. All other measured parameters were reduced to levels that meet the standards set by the Maharashtra State Pollution Control Board, demonstrating the efficacy of comprehensive treatment systems in managing pharmaceutical wastewater and the potential for reusing treated water in applications such as landscaping. Wastewater and pollutants are managed using wastewater treatment technologies at effluent treatment plants, regulated by the MPCB.

1. Introduction

Water is a vital element for all life forms and a crucial natural resource on Earth. The term wastewater encompasses stormwater, urban runoff, and various effluents, including sewage and liquid waste, originating from diverse sources such as institutions, hospitals, industrial facilities, and residential areas. As a result, wastewater becomes tainted with numerous toxic substances known to be detrimental to living organisms, necessitating treatment before environmental release (Sraavan and Matsakas 2024). The primary objective of wastewater treatment is to reduce the concentration of harmful substances prior to water discharge, thereby restoring the water supply and shielding the planet from toxic hazards. Inadequate or incorrect treatment can have severe environmental repercussions, harm aquatic life and wildlife, and potentially leading to the contamination of drinking water. Wastewater composition varies significantly depending on its source, requiring diverse treatment approaches (Sharma, Iqbal, and Chandra 2022). Treatment methods can be broadly classified into two categories: biological and chemical/physical treatment. Biological treatment leverages biological materials and bacteria, whereas chemical/physical treatment relies on physical processes and chemical reactions to achieve its goals (Jit, Chakraborty, and Sehgal 2023).

Wastewater is defined as water that has been degraded in quality due to human activities. This type of water contains a range of pollutants, including organic compounds, nutrients, heavy metals, chemicals, and disease-causing microorganisms, making it unsuitable for human consumption or release into the environment. Fortunately, straightforward wastewater treatment methods can be implemented to provide affordable sanitation and environmental safeguards while also offering the added benefit of water reuse. These methods utilize natural aquatic and terrestrial ecosystems, which can be categorized into three main types (Popuri 2017). Various wastewater treatment facilities have been designed to cater to different scales, sources, and treatment objectives. The treatment processes involve physical, chemical, and biological techniques, often applied in sequential stages, to eliminate contaminants such as solid particles and dissolved substances. Techniques like physical barriers, gravity separation, biological degradation, membrane filtration, ultraviolet light disinfection, and chemical oxidation are commonly used, with innovative approaches like nanotechnology and bio-electrochemical systems being explored to further enhance water purification for safe reuse (Kumari et al. 2023).

Mechanical treatment systems utilize natural processes within a controlled environment, often employed when land is scarce for natural system technologies. Aquatic systems, including various lagoon types such as facultative, aerated, and hydrograph-controlled release lagoons, serve as examples of this approach. Additionally, lagoon-based systems can be enhanced with pre- or post-treatments using constructed wetlands, aquaculture, or sand filtration. These systems effectively treat diverse wastewater types and operate across a broad range of weather conditions. Terrestrial systems, on the other hand, leverage the nutrients in wastewater, converting them into less accessible forms through plant growth and soil absorption, resulting in biomass that can be repurposed for multiple applications, including methane production, alcohol production, or as nutritional supplements for cattle (Jit et al. 2023).

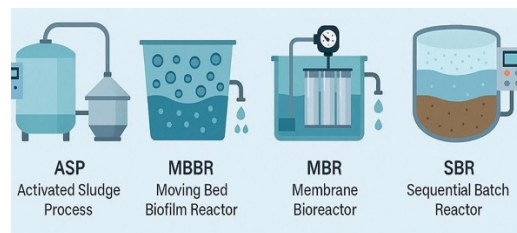


Figure 1. Types of Wastewater Treatment Technologies

Table 1. Comparison on various types of Wastewater Treatment Technologies

Feature	ASP (Activated Sludge Process)	MBBR (Moving Bed Biofilm Reactor)	MBR Membrane Bioreactor)	SBR (Sequencing Batch Reactor)
Process Type	Aeration + Settling	Biofilm + Aeration	Biological treatment + Membrane filtration	Time-sequenced batch process
Footprint	Large	Medium	Compact (30–50% smaller)	Medium to Large
Effluent Quality	Moderate (needs polishing)	Good (needs polishing)	High (near potable quality)	Good (needs polishing)
Water Reuse Capability	Limited	Suitable with polishing	High (flushing, gardening)	Medium
Energy Consumption	Moderate	Moderate	High	Moderate
Sludge Production	High	Low to Moderate	Low	Moderate
O&M Complexity	Low	Medium	High (membrane care needed)	Medium to High
CapEx (Initial Cost)	Low	Medium	High	Medium

Annually, the global consumption of pharmaceutical products exceeds 100,000 tons, resulting in significant environmental contamination from active pharmaceutical ingredients (APIs) during production, usage, and disposal. The wastewater generated by this industry is highly variable in terms of flow rate and composition, posing treatment challenges. Several biological treatment technologies are available, including activated sludge treatment, moving bed biofilm reactors (MBBR), anaerobic digestion, and targeted micro-pollutant removal. However, the presence of toxic and inhibitory contaminants, as well as oxidation-resistant organic compounds, can hinder treatment effectiveness. To address these issues, many pharmaceutical companies rely on specialized waste management services, incurring substantial costs for liquid waste disposal. In this context, vacuum evaporators emerge as a highly efficient and cost-effective solution for treating pharmaceutical industry wastewater, offering a viable alternative for managing these complex effluents (Popuri 2017).

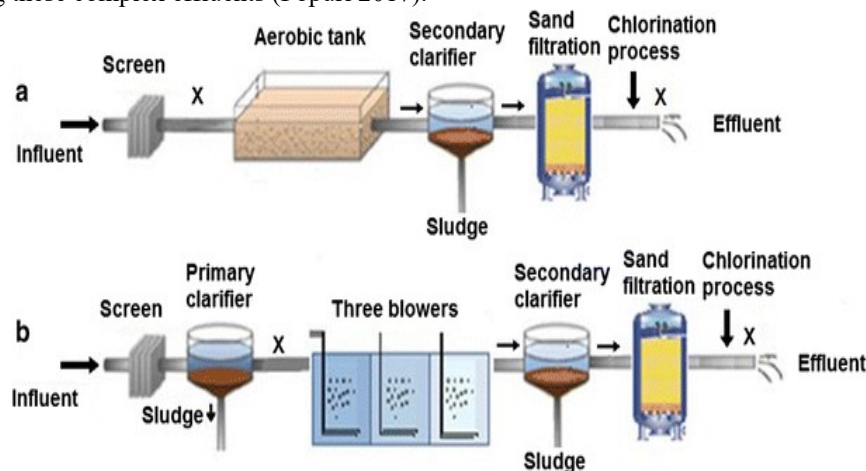


Figure 2. Work flow diagram of Wastewater Treatment Technologies

In the pharmaceutical industry, purified water serves two key purposes: it is utilized in the production of specific products and also employed for sanitizing equipment, containers, and packaging materials. This dual use generates effluents that contain residual chemical substances, including remnants of pharmaceuticals and cleaning agents. According to the World Health Organization, the pharmaceutical sector produces a diverse range of waste that enters environmental water systems through effluents from manufacturing facilities. The quantity and composition of wastewater from this sector vary significantly due to differences in

production methods and the formulation of pharmaceutical products (Kanawade 2015).

In pharmaceutical manufacturing, various substances are utilized, including chemical products, cleaning agents, and active pharmaceutical ingredients (APIs), which serve as the foundation for medicines aimed at preventing and treating diseases. These pollutants, known as "emerging contaminants" (ECs), are released into water and remain unregulated. They originate from everyday human activities, such as personal care and healthcare, and are characterized by diverse origins and chemical compositions. Despite their presence, relatively little is understood about the environmental and human health impacts of these emerging contaminants, also referred to as micro contaminants (Sahithya 2016).

Pharmaceutical wastewater exhibits significant variability, comprising a broad spectrum of toxic substances, including active pharmaceutical ingredients, solvents, antibiotic and hormonal residues, suspended solids, toxic organic compounds, heavy metals, and effluents with imbalanced pH levels, as well as high chemical and biological oxygen demands. To mitigate environmental pollution and adhere to rigorous regulatory requirements, treatment of pharmaceutical wastewater involves a multi-stage Effluent Treatment Plant, incorporating physical, chemical, biological, and advanced processes to eliminate complex contaminants, such as active ingredients, high oxygen demands, and salts, utilizing technologies like coagulation, sequential batch reactors, advanced oxidation processes, reverse osmosis, and activated carbon, which are often integrated into hybrid systems to meet stringent standards for discharge and reuse (Patil 2014).

Pharmaceutical facilities can implement effluent treatment processes that enable the reuse of treated water, promoting sustainable water consumption. By doing so, they reduce their reliance on freshwater sources and mitigate the ecological effects of water extraction. Compliance with environmental laws and effective effluent treatment are crucial for the long-term success of pharmaceutical operations, as they prevent disruptions caused by legal issues, public backlash, or environmental accidents. Additionally, effluent treatment plants often incorporate sludge management procedures, which can involve extracting valuable materials for reuse, thereby supporting resource conservation and sustainability (Kotwani et al. 2023).

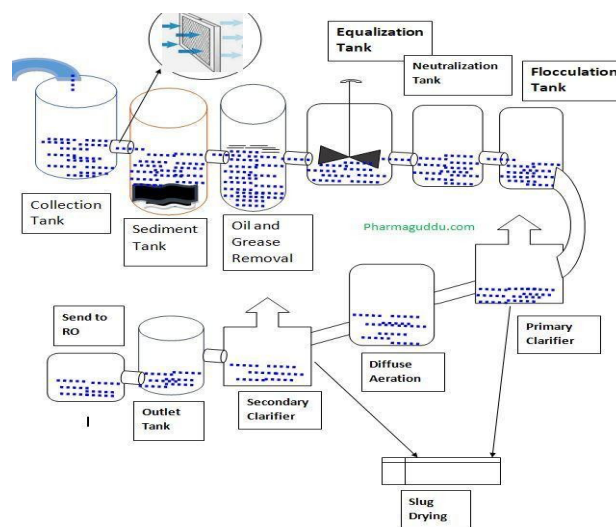


Figure 3. Process Flow diagram of Wastewater in Effluent Treatment Plants

Industries seeking to reduce their environmental footprint and foster sustainability rely heavily on Effluent Treatment Plants. These facilities effectively eliminate contaminants from industrial wastewater, thereby safeguarding public health, conserving ecosystems, and adhering to environmental standards. Additionally, they facilitate water recycling and resource preservation, enabling industries to adopt environmentally responsible practices. The wastewater treatment process within these systems is essential to achieving these goals, as it ensures the effective treatment of wastewater for reuse, ultimately decreasing the burden on natural water resources and solidifying their importance in industrial water management (Gadipelly, Rathod, and Marathe 2014).

In the current era of increased environmental consciousness and strict regulations, implementing a reliable effluent treatment plant has become a necessity for industries to operate responsibly. As industrial activities expand, the need for efficient wastewater management solutions grows, with effluent treatment plants playing a vital role in the transition to more environmentally friendly and sustainable practices. By adopting state-of-the-art treatment systems, industries can contribute to a cleaner and safer environment while ensuring their long-term economic sustainability. These advanced systems also offer effective treatment of liquid waste, enabling industries to meet environmental standards and reduce their ecological footprint through efficient chemical

treatment processes (Patil and Chaudhari 2019).

This paper aims to examine and assess the wastewater treatment technologies utilized in the pharmaceutical sector, with particular emphasis on the Effluent Treatment Plant (ETP) system. Its objective is to investigate the properties of pharmaceutical wastewater and evaluate the efficacy of different treatment methods, including physical, chemical, and biological processes, in reducing organic pollutants, toxic substances, and contaminants like active pharmaceutical ingredients within ETPs.

2. Literature Review

Numerous studies have explored wastewater treatment solutions to overcome existing challenges, with Effluent Treatment Plant systems gaining widespread acceptance due to their capacity to combine physical, chemical, and biological methods. Research has shown that traditional treatment approaches, including coagulation-flocculation, activated sludge processes, and advanced oxidation methods, are effective in minimizing pollutants such as biochemical oxygen demand, chemical oxygen demand, and suspended solids. This review aims to compile recent research on pharmaceutical wastewater treatment technologies, assess their effectiveness, and pinpoint areas for improvement regarding efficiency, sustainability, and adherence to regulations.

J. Shanthi Sravan, et.al. (2024) reveal the potential of integrated approaches for wastewater treatment, focusing on green energy production, resource recovery, and low-carbon fuel generation. Various biological treatment methods, including bioremediation, electro-coagulation, and bio-electrochemical systems, are examined in relation to non-genetically modified metabolic processes. The hybridization of carbon, metal, and nano-based materials enhances fermentative biocatalyst activity, addressing limitations of traditional methods. Nanotechnology offers innovative solutions to overcome conventional process constraints, enabling improved waste remediation and resource utilization. Overall, integrated strategies show promise as alternatives to enhance biological wastewater treatment efficiency, supporting the circular economy and environmental conservation.

Dhruvin Sojitra, et.al. (2024) found that a reliability analysis of Common Effluent Treatment Plants (CETPs) using official government data revealed significant variability in reliability levels. The analysis, which utilized a established methodology to calculate reliability coefficients, showed that compliance rates for key parameters differed substantially across CETPs. Specifically, the reliability levels ranged from 7 to 99.99% for chemical oxygen demand, 25.5 to 99.99% for biochemical oxygen demand, 46.8 to 99.4% for suspended solids, 41.2 to 99.8% for ammoniacal nitrogen, and 85.2 to 98.1% for phenolic compounds. These disparities suggest that most CETPs are not functioning properly. To improve reliability to 95%, the study determined the required operating mean concentrations for these parameters, providing a valuable framework for individual wastewater treatment plants to achieve optimal performance and benefit the wastewater community.

Bikram Jit Singh, et.al. (2023) found that emerging research areas, such as nanotechnology and bioremediation, are gaining prominence, and circular economy principles play a crucial role in wastewater management. The study provides a comprehensive overview of current industrial wastewater management practices, emphasizing the need for a holistic approach that combines regulatory, technological, and sustainability aspects. It reveals gaps and opportunities for future investigation, promoting interdisciplinary research and stakeholder collaboration. The findings are useful for policymakers, practitioners, and researchers, enabling them to tackle challenges and leverage opportunities in industrial wastewater management.

Harita Kumari, et.al. (2023) found that doping, nanocomposite formation, and core-shell nanostructures of metal oxides offer unique advantages, particularly with rare-earth doped metal oxides, which rapidly interact with functional groups due to their 4f empty orbitals. This review outlines synthesis procedures for rare-earth doped metal oxides and nanocomposites, their efficiency in degrading organic pollutants, and potential sources. The primary objective is to present high-performing, cost-effective strategies with potential benefits for future industrial applications.

Pooja Sharma, et.al. (2022) found that an examination of physico-chemical pollution parameters and the presence of toxic elements in the wastewater of four PPI facilities in the Uttar Pradesh and Uttarakhand regions of India revealed high levels of pollution and heavy metals. The study's results indicated that the wastewater discharged from these facilities contained elevated pollution parameters and heavy metals, exceeding permissible limits. The research suggested that treating PPI wastewater at a tertiary stage is necessary before releasing it into the environment. The wastewater from these facilities was shown to contain a range of contaminants, including biological oxygen demand, chemical oxygen demand, total solids, total dissolved solids, total suspended solids, and ions, as well as toxic metals. The persistent presence of high biological oxygen demand, chemical oxygen demand, and metals in the environment poses a hazard to aquatic organisms. Furthermore, the lack of attention to tertiary treatment of wastewater allows metallic compounds to remain in the wastewater stream, compromising the health of humans, animals, and the environment.

Anita Srivastava, et.al. (2022) found that recent advancements in biotechnological processes offer insights into the economic and cutting-edge technologies used in treating textile effluents, with integrated biotechnological approaches and bioprocess engineering presenting opportunities for cost-effective management. The review highlights studies on advanced in-silico and multiomics approaches, including proteomics, genomics, and metabolomics, while also identifying gaps in effluent treatment operations and showcasing case studies on waste effluent treatment and recycling in India.

Dr. Arif Khan, et.al. (2021) found that a study evaluating the performance of a 20 MLD Sewage Treatment Plant utilizing the Sequential Batch Reactor (SBR) process at Old Somal-wada, Nagpur, India, yielded promising results. The research investigated the efficacy of a pilot-scale SBR process in treating various wastewater quality parameters, including turbidity, total suspended solids (TSS), total solids (TS), nitrogen compounds (ammonia, nitrite, and nitrate), phosphate, chemical oxygen demand (COD), and 5-day biological oxygen demand (BOD5) in municipal wastewater. The effluent concentrations of the targeted parameters in the proposed SBR system were found to be below the local standards, outperforming the North Sewage Treatment Plant in Dharan, Eastern province, Kingdom of Saudi Arabia (KSA), in terms of BOD5, COD, total nitrogen, and phosphate treatment efficiencies. These findings suggest that SBR technology is suitable for wastewater treatment in remote areas of the KSA, offering a high potential for reusability and sustainable wastewater management.

S. S. Kekane, et.al. (2020) found that water pollution caused by heavy metals is a significant concern. Water samples were collected monthly from rivers near industrial areas between August 2017 and July 2018. Using Atomic Absorption Spectrophotometry, the levels of Iron, Copper, Zinc, Manganese, Nickel, Chromium, Cobalt, and Lead were measured. The study revealed that concentrations of certain heavy metals in the area are increasing at an alarming rate. The results indicated that metal concentrations vary unevenly from east to west, as water flows towards the western zone and into the sea. It was observed that industrialization in the area is contributing to the rising metal concentrations. Sampling stations more heavily impacted by industrial discharge showed higher metal concentrations. Notably, significant contamination was detected for metals like Copper, Chromium, and Nickel during the study.

Ashwini V. Padalkar, et.al. (2018) found that the results of the research and the coefficient of determination values from the CETP data revealed the rates of pollutant removal over time, identifying areas of concern and potential solutions. The study noted that, with the exception of O&G, parameters such as BOD, COD, and TSS exhibited variability in removal efficiency and reliability. To address this issue, it is recommended that effluent release to the CETP be standardized in terms of hydraulic and organic loading, and that treatment processes, particularly primary clarifloculators and aeration tanks, be optimized to improve overall performance.

Ashok Kumar Popur, (2017), found that the disposal or treatment of bulk drug industry effluents poses a significant challenge due to their detrimental impact on the environment. This approach entails conducting tests for parameters such as COD, BOD, TDS, and SS at the Common Effluent Treatment Plant (CETP). The results are evaluated at various stages of effluent treatment, comparing the measured properties to standard guidelines. Key factors, including performance, efficiency, energy consumption, and economic viability, are assessed for each unit operation and compared to available design data, facilitating the design of new plants with similar characteristics and increased capacity.

Table 2. Comparative Table for Previous Research Done

Author / Year	Purpose of Study	Methodology	Key Results / Findings
J. Shanthi Sravan et al., 2024	To explore integrated wastewater treatment strategies for green energy generation and resource recovery	Review of biological, electrochemical, advanced oxidation, and nano-enabled treatment processes	Integrated and hybrid treatment approaches enhance pollutant removal, resource recovery, and support circular economy goals
Dhruvin Sojitra et al., 2024	To assess the reliability of CETPs based on compliance with discharge standards	Statistical reliability analysis using government monitoring data	Wide variation in treatment reliability; many CETPs underperform due to operational inefficiencies
Bikram Jit Singh et al., 2023	To identify emerging technologies and sustainability frameworks	Systematic literature review (SLR)	Highlighted the importance of nanotechnology, bioremediation, and circular
Harita Kumari et al., 2023	To evaluate rare-earth doped metal oxide nanomaterials for organic pollutant degradation	Review of synthesis methods and degradation mechanisms	Nanocomposites demonstrated high efficiency and cost-effectiveness for pollutant removal
Pooja Sharma et al., 2022	To analyze pollution parameters and toxic metals in pharmaceutical wastewater	Physico-chemical analysis of wastewater samples from pharmaceutical industries	High BOD, COD, and heavy metals exceeded permissible limits; tertiary treatment deemed necessary
Anita Srivastava et al., 2022	To review advancements in biotechnological treatment of textile effluents	Review of integrated Bioprocesses and multi-omics approaches	Advanced biotechnological techniques show promise but face operational and economic challenges
Dr. Arif Khan et al., 2021	To evaluate the performance of SBR technology in wastewater treatment	Pilot-scale SBR performance analysis	SBR showed high removal efficiency for BOD, COD, nutrients, and solids, meeting discharge standards
S. S. Kekane et al., 2020	To assess heavy metal pollution in industrial water bodies	Seasonal sampling and AAS analysis	Elevated levels of heavy metals linked to industrial discharge, posing environmental risks
Ashwini V. Padalkar et al., 2018	To analyze pollutant removal efficiency and reliability of CETPs	Statistical analysis of CETP operational data	Inconsistent removal efficiencies observed; process optimization recommended
Ashok Kumar Popur, 2017	To evaluate CETP performance in bulk drug industries	Comparative analysis of influent–effluent parameters and unit operations	Highlighted need for improved design, efficiency, and energy optimization in CETPs

3. Research Gap

The body of research on wastewater treatment technologies has made significant strides, encompassing biological processes, advanced oxidation methods, nanotechnology, and integrated systems. Nevertheless, notable shortcomings persist in managing pharmaceutical wastewater using Effluent Treatment Plant (ETP) systems. The majority of research concentrates on either cutting-edge or emerging technologies at a theoretical or small-scale level, with inadequate consideration for their implementation in existing pharmaceutical ETPs on a larger scale. Moreover, although assessments of the reliability and performance of Common Effluent Treatment Plants (CETPs) and Sewage Treatment Plants (STPs) have been undertaken, there is a scarcity of in-depth, plant-specific examinations that account for the intricate and varied composition of pharmaceutical wastewater, including active pharmaceutical ingredients and persistent organic pollutants. The existing literature highlights a deficiency in thorough evaluations of tertiary and advanced treatment phases within ETPs, despite the presence of residual contaminants following conventional treatment. Moreover, the long-term stability, cost-effectiveness, and adherence to regulations of integrated ETP systems in the pharmaceutical sector have received limited attention. As a result, there is a pressing need for comprehensive studies that integrate performance analysis, advanced treatment integration, and sustainability assessments of ETP-based wastewater treatment systems, specifically designed for pharmaceutical industrial effluents.

4. Research Methodology

The chosen study area comprises industrial hubs with a high concentration of pharmaceutical manufacturing facilities, where Effluent Treatment Plants (ETPs) are typically implemented to handle wastewater from production, labs, utilities, and supporting activities. These ETPs are engineered to purify mixed industrial wastewater prior to release or repurposing, adhering to MPCB regulations.

This research focused on an Effluent Treatment Plant with a treatment capacity of 150 cubic meters per day, equivalent to 150 kiloliters daily. Throughout the study, the plant operated near its full capacity, with an average intake of around 150 cubic meters daily. It processed a combined industrial wastewater stream from various sources, including production areas, labs, and support facilities. The treatment process involved several phases: preliminary, primary, secondary biological, and final polishing stages. Overall, the system adhered to a standard ETP design, utilizing physical, chemical, and biological methods to achieve effective wastewater treatment.

ETP DETAILS

Effluent treatment plant Flow Diagram:

Capacity of ETP – 150 m³/day

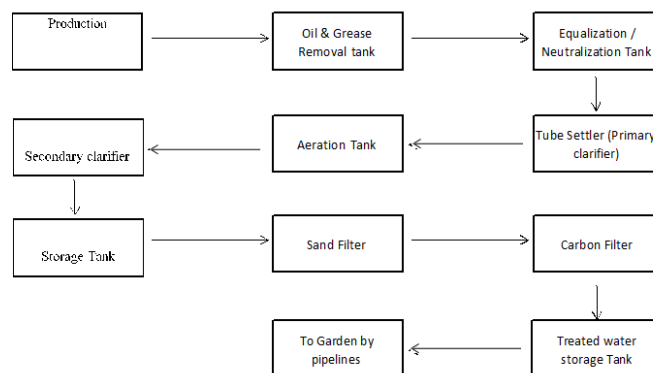


Figure 4. Flowchart of Effluent Treatment Plants Capacity of ETP – 150 m³/day

5. Treatment Process Configuration

The treatment process begins with the removal of oil and grease from the raw effluent, followed by equalization and neutralization

to standardize wastewater characteristics and balance pH levels. The effluent then undergoes primary clarification in a tube settler, where gravity settling removes settleable solids. Next, the clarified wastewater enters a secondary biological treatment system, which includes an aeration tank that operates under aerobic conditions to break down organic matter. To optimize nitrogen removal, the system uses pre-denitrification under anaerobic or anoxic conditions, followed by nitrification under aerobic conditions. Secondary clarifiers support the biological treatment by separating biomass. A fraction of the stabilized secondary sludge is returned to the primary clarifier, which enhances its settling characteristics and boosts the average sludge retention time, resulting in improved treatment efficiency. The surplus sludge, a mixture of primary and secondary sludge, is sent to sludge processing facilities for concentration and moisture removal. After stabilization, the sludge undergoes anaerobic breakdown, producing biogas that is used to heat the digesters, thus aiding in energy conservation. The clarified wastewater from secondary treatment is further purified by passing it through filters containing sand and activated carbon to eliminate remaining particulate matter, color, and organic compounds. The purified water is then held in a storage reservoir and reused for irrigation through a network of pipes, facilitating partial water reuse.

6. Analysis and Results

Wastewater samples were gathered from the ETP inlet and outlet at consistent intervals throughout the study. Eighteen sample sets were examined to assess treatment effectiveness. Standard protocols for grab sampling were followed to guarantee accurate representation of wastewater properties. The samples underwent analysis for crucial parameters such as pH, COD, BOD, TDS, TSS, Chloride, Sulphate, and Oil & Grease content. All tests adhered to established methodologies endorsed by reputable organizations for examining wastewater. The ETP's performance was evaluated by analyzing the difference in influent and effluent levels of key parameters. Efficiency was calculated as the percentage decrease in pollutants throughout various treatment phases. Final effluent quality was compared to SPCB discharge standards to determine compliance with regulations.

The analytical findings were organized and examined to detect patterns in the variability of incoming wastewater and the quality of treated effluent. Special attention was given to decreasing indicators of organic pollution, including biochemical oxygen demand and chemical oxygen demand, as well as adhering to limits for solid particles, dissolved substances, and oil and grease content. The performance of the integrated effluent treatment plant in managing mixed industrial wastewater was evaluated based on its overall ability to remove pollutants and consistently meet regulatory requirements.

The table below outlines the physicochemical properties of wastewater samples taken at the Effluent Treatment Plant's inlet across eighteen events. Influent wastewater pH levels stayed within a slightly alkaline to near-neutral range, fluctuating between 7.26 and 7.91, suggesting stable conditions that are conducive to biological treatment.

Table 3. Analytical Results on Effluent Treatment Inlet

Analysis on Effluent Treatment Inlet									
Sr. No.	PH	COD	TDS	TSS	Chloride	Sulphate	Oil & Grease	&	BOD
1	7.9	1168	2280	170	770	222	6		381
2	7.84	1152	2240	180	810	216	4		392
3	7.55	8280	4600	240	1579	198	6		2380
4	7.62	8560	3840	170	1670	204	7		2110
5	7.84	7960	4480	190	1840	210	5		2260
6	7.91	8160	3160	240	1711	215	4		2140
7	7.45	7720	4400	280	1920	220	6		2370
8	7.32	8000	4640	270	1630	219	7		401
9	7.79	1120	2120	110	790	220	4		442
10	7.64	1144	2600	120	815	211	5		392
11	7.81	1112	2040	110	822	228	3		384
12	7.62	1104	2080	130	833	241	4		405
13	7.7	1210	2110	140	792	234	3		398
14	7.68	1180	2090	160	784	226	2		406
15	7.26	840	2272	162	734	218	2		228
16	7.6	1168	2280	170	865	245	3		262
17	7.45	942	2360	190	842	232	2		278
18	7.62	1280	2860	185	788	223	2		267

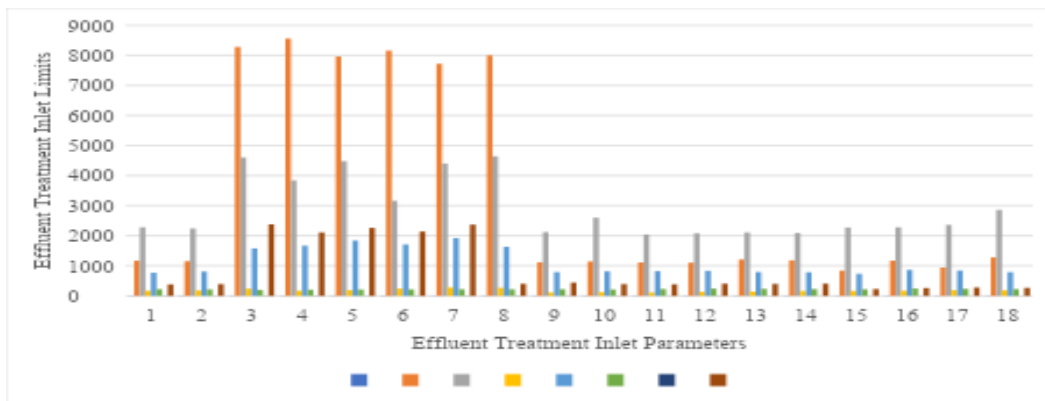


Figure 1. Results on Effluent Treatment Inlet

The incoming wastewater showed a substantial organic burden, as evidenced by the significant fluctuations in Chemical Oxygen Demand (COD) levels, which spanned from 840 mg/L to 8560 mg/L, and Biochemical Oxygen Demand (BOD) levels, which fell between 228 mg/L and 2380 mg/L. The high COD and BOD levels in multiple samples suggest the presence of both biodegradable and non-biodegradable organic substances, typical of industrial and pharmaceutical wastewater. The Total Dissolved Solids (TDS) concentrations varied from 2040 mg/L to 4640 mg/L, and the Total Suspended Solids (TSS) concentrations ranged from 110 mg/L to 280 mg/L, indicating a considerable amount of dissolved and suspended matter in the wastewater. The high levels of solids can negatively impact treatment effectiveness if not properly managed during the initial treatment phases. The levels of chloride and sulphate fluctuated significantly, with chloride concentrations spanning 734-1920 mg/L and sulphate levels between 198-245 mg/L. The presence of these high inorganic compound levels is attributed to the utilization of salts and chemicals in industrial activities. At the inlet, oil and grease levels were low yet measurable, falling within the 2-7 mg/L range, suggesting inputs from mechanical processes, utility systems, or supporting operations. The characteristics of the inlet wastewater exhibit notable fluctuations and substantial pollutant loads, highlighting the necessity for an efficiently run and well-designed ETP to achieve effective treatment and adherence to discharge regulations. The table below shows the analysis of wastewater treated at the Effluent Treatment Plant's outlet, based on eighteen monitored samples. The treated water's pH levels ranged from 7.45 to 8.10, demonstrating successful pH management and conditions suitable for safe release and reuse.

Table 4. Analytical Results on Effluent Treatment Outlet

Sr. No.	PH	COD	TDS	TSS	Chloride	Sulphate	Oil & Grease	BOD
1	8.01	180	760	40	160	98	0	40
2	7.94	190	750	50	450	102	0	35
3	8.1	230	1900	80	510	109	0	80
4	7.8	240	2000	78	520	110	0	90
5	7.9	220	2050	82	530	210	0	70
6	7.7	240	1940	76	550	170	0	80
7	7.88	210	1150	85	460	90	0	90
8	7.66	240	1850	45	450	89	0	75
9	7.84	190	950	40	290	90	0	80
10	7.81	180	1100	30	310	85	0	74
11	7.92	205	810	35	305	90	0	84
12	7.75	210	790	38	300	75	0	90
13	7.99	179	990	40	238	70	0	88
14	7.8	170	910	46	270	80	0	92
15	7.45	150	890	48	240	70	0	40
16	7.8	165	880	50	270	72	0	45
17	7.55	140	810	55	250	88	0	35
18	7.7	160	780	58	170	90	0	30

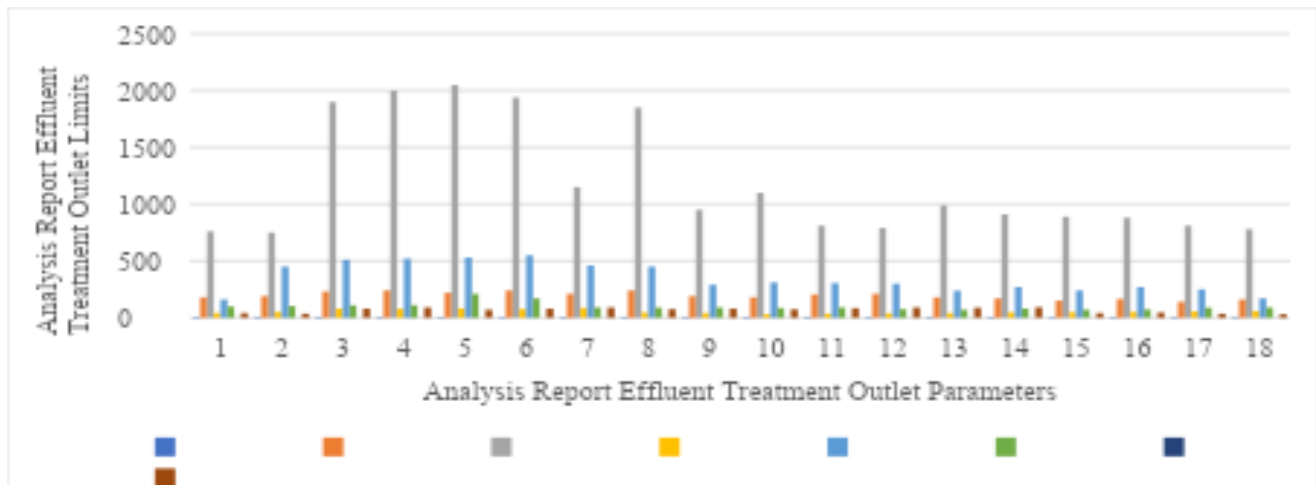


Figure 2. Results on Effluent Treatment Outlet

The Chemical Oxygen Demand (COD) readings fluctuated between 140 mg/L and 240 mg/L, indicating a significant decrease in organic content resulting from the integrated primary, secondary, and tertiary treatment stages. The Biochemical Oxygen Demand (BOD) levels fell within the range of 30 mg/L to 92 mg/L, showcasing the effective breakdown of organic substances. These readings comply with the specified discharge standards, validating the efficacy of the biological treatment systems. Total Dissolved Solids (TDS) levels were found to be between 750 mg/L and 2050 mg/L, staying under the permitted limit. With Total Suspended Solids (TSS) levels ranging from 30 mg/L to 85 mg/L, the treatment process demonstrated efficient particulate matter removal during the clarification and filtration phases.

The levels of chloride and sulphate in the treated effluent were substantially lower than those in the influent, with chloride concentrations between 160 mg/L and 550 mg/L and sulphate levels between 70 mg/L and 210 mg/L. These values fell within the allowable limits established by regulatory bodies. The complete removal of oil and grease from all treated effluent samples underscores the efficacy of the oil and grease removal system and subsequent treatment stages. The outlet analysis shows that the ETP consistently generates high-quality treated effluent that meets discharge requirements and is fit for non-potable reuse, such as irrigation and landscaping purposes.

The State Pollution Control Board (SPCB) sets limits for industrial wastewater release to safeguard the environment and uphold water quality standards. Although a specific numerical range for the pH of treated effluent is not rigidly defined, it should be close to neutral or mildly alkaline to avoid harming aquatic ecosystems.

Table 5. Analytical Results on State Pollution Control Board

State Pollution Control Board							
PH	COD	TDS	TSS	BOD	Chloride	Sulphate	Oil & Grease
--	250	2100	100	100	600	1000	10

The results indicate that the permissible limits for Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD) are 250 mg/L and 100 mg/L, respectively, to ensure adequate reduction of organic pollutants and preservation of dissolved oxygen levels in water bodies. The Total Dissolved Solids (TDS) limit is set at 2100 mg/L to regulate the concentration of dissolved inorganic salts. Meanwhile, Total Suspended Solids (TSS) must not exceed 100 mg/L to prevent sedimentation and turbidity problems. The allowable concentrations of chloride and sulphate are capped at 600 mg/L and 1000 mg/L to mitigate salinity and scaling effects.

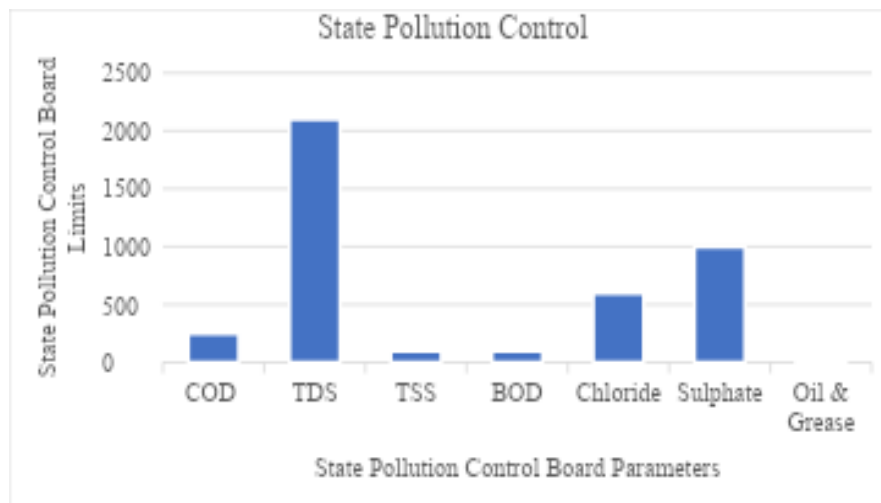


Figure 3. Results on State Pollution Control

Additionally, oil and grease levels should be kept below 10 mg/L to prevent surface water contamination and potential harm to aquatic life. These standards provide crucial benchmarks for assessing the effectiveness of Effluent Treatment Plants (ETPs) in producing environmentally safe treated wastewater for discharge or reuse.

7. Discussion

The examination of incoming wastewater revealed significant fluctuations in organic and inorganic content, typical of pharmaceutical discharge. Chemical oxygen demand and biological oxygen demand measurements varied widely, spanning 840–8560 mg/L and 228–2380 mg/L, respectively, which suggests the coexistence of easily broken-down and persistent substances. Total dissolved solids and total suspended solids concentrations were also high, indicating the presence of dissolved salts and particulate matter. The wastewater treatment plant effectively decreased organic content through a multi-step process involving primary settling, aerobic biological treatment, and advanced polishing, resulting in chemical oxygen demand and biological oxygen demand levels within acceptable limits of 140–240 mg/L and 30–92 mg/L. Total suspended solids were reduced to 30–85 mg/L, and total dissolved solids, including chloride and sulfate, remained below regulatory limits. Oil and grease were entirely eliminated, demonstrating the efficacy of preliminary treatment stages. The recycling of secondary sludge and anaerobic digestion enhanced sludge stability and energy production, while tertiary treatment using sand and activated carbon filtration improved effluent quality for potential reuse. The findings confirm that the comprehensive treatment plant design can manage highly variable pharmaceutical wastewater while maintaining environmental standards.

8. Conclusion and Future Scope

The Effluent Treatment Plant examined successfully removed pollutants from pharmaceutical wastewater, resulting in significant decreases in contaminants such as chemical oxygen demand, biological oxygen demand, total dissolved solids, total suspended solids, chloride, sulfate, and oil and grease. The plant's effluent consistently complied with regulatory discharge standards, showcasing its dependability and operational effectiveness. By combining physical, chemical, and biological treatment methods with sludge recirculation and anaerobic digestion, the plant enhanced pollutant elimination, stabilized sludge, and recovered energy. The treated water is of sufficient quality for reuse in non-potable applications, aiding water conservation in industrial settings. This study underscores the importance of well-designed and properly managed Effluent Treatment Plants for environmentally sustainable wastewater management in the pharmaceutical sector. Future research in pharmaceutical wastewater management may investigate various approaches to improve treatment effectiveness, environmental protection, and resource utilization. Integrating cutting-edge technologies, such as membrane bioreactors, UV treatment, or chemical oxidation, can help eliminate remaining microcontaminants and pharmaceutical byproducts that conventional effluent treatment systems fail to remove. Implementing real-time monitoring systems with online sensors to track parameters like chemical oxygen demand, biological oxygen demand, and total dissolved solids enables continuous evaluation of plant operations and prompt identification of process anomalies, thereby enhancing overall reliability. Strategies to optimize energy use, including improved biogas capture and the use of alternative energy sources, can help minimize operational expenses and decrease the environmental impact of treatment plants. Additionally, increasing the reuse of treated wastewater for purposes like industrial cooling systems, boiler



feedwater, and agricultural irrigation can further decrease the demand for freshwater and promote environmentally sustainable water management practices.

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