Reimagining Urban Water Reuse: Evaluating the Performance of a Membrane Bioreactor Sewage Treatment Plant

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Abstract

Increasing city populations call for more efficient and sustainable treatment of wastewater to uphold environmental standards. This research evaluates the MBR system of capacity 6 MLD (million litres per day), a Sewage Treatment Plant in Palava City, Maharashtra, one of India's well-known upcoming private cities. Membrane Bioreactor (MBR) systems treat sewage biologically and through advanced technology membranes to provide high-quality effluent that is fit for reuse. The performance evaluation is being carried out on the basis of crucial water quality parameters: BOD(biological oxygen demand), COD(carbon oxygen demand), TSS(total suspended solids), pH, and fecal coliforms from SCADA logs, laboratory test reports, and chemical dosing protocols of early 2025. The results indicate that the plant surpasses the Central and State Pollution Control Boards' standards for discharged water quality, with BOD <1 mgL^{-1} and microbial count presenting a non-detectable occurrence. Long-term operational stability is also sustained with the help of automated monitoring systems and allows for quick debugging of process parameters.

1. Introduction

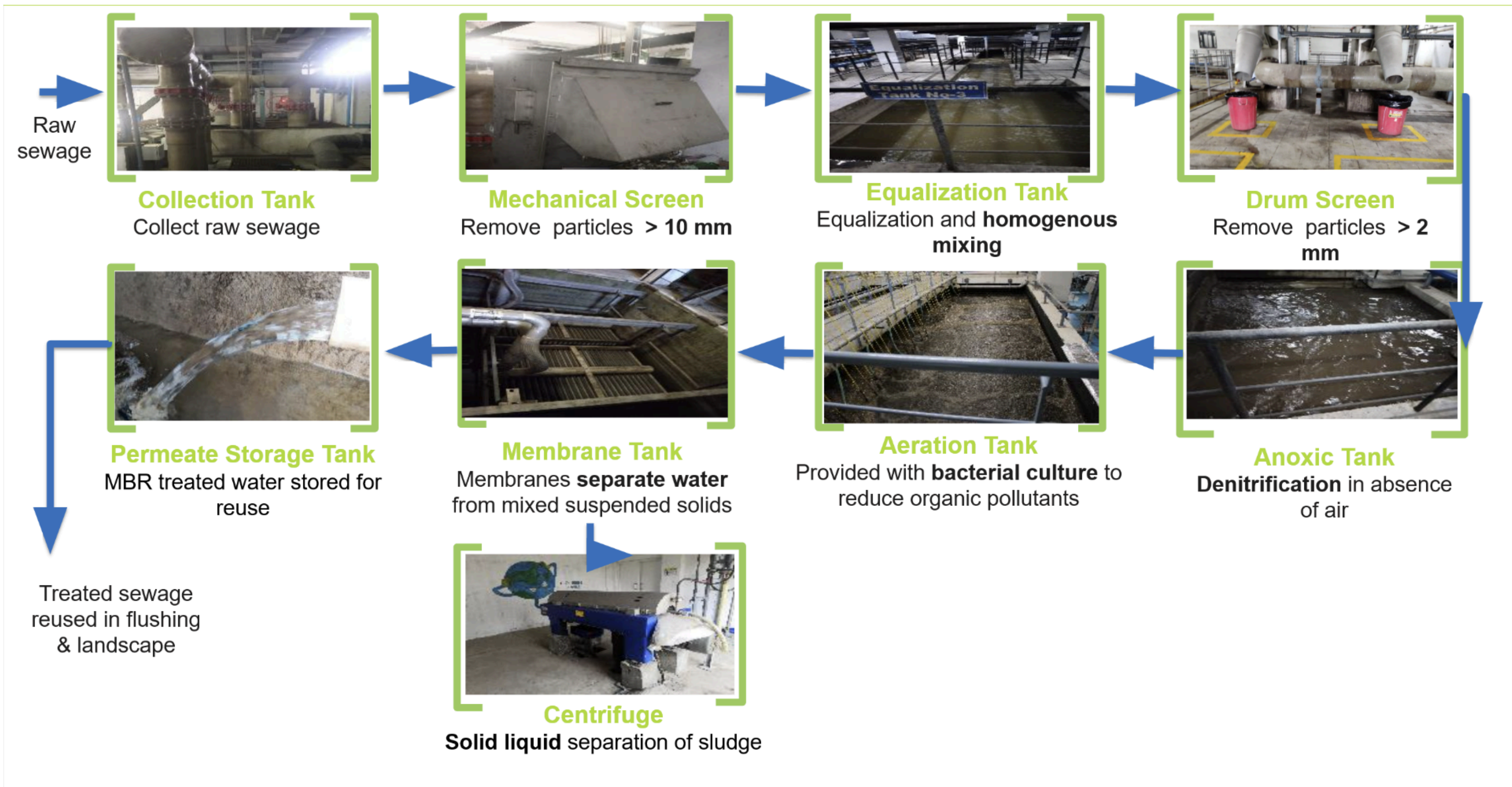
Urban wastewater management is a truly complex and multifaceted process, particularly brought forth by rapid urbanization, resulting in increasing water stress and evolving regulatory norms. With cities spreading out and freshwater sources shrinking away, sewage treatment cannot be the sole focus; water recovery for reuse is equally important, if not more. Theoretically, conventional systems should be able to treat municipal sewage; yet, there are many practical concerns. For instance, there are various inconsistencies in meeting parameters ranging from degradation, energy use, and raw sewage quality, to microbe count in the effluent, especially in urban scenarios where space may be limited.

This paper studies a sewage treatment plant at Palava City in Maharashtra. It uses MBR (Membrane Bioreactor) technology, a step ahead in the treatment technologies, whereby biological processes occur simultaneously with the ultrafiltration membranes to produce a disinfected water source that can be non-potably reused for flushing, irrigation, and HVAC-type activities, while also meeting the standard for intake. Whereas a conventional gravity-based treatment plant occupies landscape space, this STP is housed below a multi-level parking. The majority of the processes are also automated and can be monitored through a SCADA system.

2. Site Context and MBR Technology

MBR technology, as discussed, is a modern wastewater treatment that employs biological decomposition with ultrafiltration, allowing high efficiency, compact systems that fit well in dense urban environments. Consequently, Palava City Sector 2 employs 3 such STPs housed under MLPs(multi-level parkings). To maintain a considerably small form factor while also remaining efficient and meeting standards, Palava's STP is pump-reliant between stages, and has a sequence optimized for consistency, effluent quality, and reuse. However, a lot of its processes are also aided by gravity due to its vertical nature.

Figure 1. Treatment Process



Referring to Figure 1, above, the entire process is documented. It is also further elaborated from 2.1 through 2.10 below.

2.1 Collection Tank

All domestic waste from the residential buildings is amalgamated in a collection tank, which evens out a lot of the input from the different buildings. While no treatment takes place, it plays an important role in absorbing flow spikes or shocks, and thus is divided into three collection tanks: two operational and one on standby in case of emergency. This helps safeguard all the further units from overload and maintains pump health. Additionally, there are also sensors in the collection tank with individual negative feedback loops to avoid overflows or dry starts. In short, the collection tank collects and stablises the raw sewage.

2.2 Mechanical Screen

From the collection tank, all the effluent is then passed through 10mm screens that can remove visible, larger debris, along with solid organic matter. This step particularly reduces the TSS load on the plant and is essential in protecting the pumps, blowers, and membranes from clogging and wear and tear.

2.3 Equalization Tank

The equalization tank contains mixers that help in maintaining wastewater conditions, ensuring the entire mixture is homogenous. This allows the further modules to receive a consistent flow, regardless of any spikes. This is particularly helpful in the anoxic tank and the actual membrane module, as this avoids inefficiencies and transient overloading, both of which could lead to issues in the denitrification process and membrane fouling.

2.4 2 mm Drum Screen

Proceeding through, the sewage passes through a 2 mm perforated drum screen, which eliminates very fine suspended matter, further reducing TSS. Further, it acts as a protection for the ultrafiltration membranes against physical blockages and helps reduce their cleaning frequency. SCADA feedback from this stage is used to flag performance inefficiencies upstream. Likewise, the buildup of grease that may compromise membrane performance can also be identified and rectified.

2.5 Anoxic Tank

In the anoxic tank, denitrifying bacteria work in the absence of oxygen to convert nitrate(NO_3^-) into nitrogen gas(N_2). The anoxic tank must maintain a good sludge recirculation from the membrane tank: if the upstream loads vary excessively, conditions may not be optimal, and thus have a subsequent effect on nutrient removal. The plant measures ORP (Oxidation-Reduction Potential) to optimize its denitrification cycles, once again using SCADA systems to rectify any changes in conditions.

2.6 Aeration Tank

In the aeration tank, bacteria aerobically(in the presence of oxygen) degrade dissolved organic compounds. Bubble diffusers maintain a DO(dissolved oxygen) of 2.0-2.5 mgL^{-1} under SCADA control to match microbial demand to blower energy input. When operated properly, this process ensures fast degradation of BOD/COD and stable MLSS levels. Energy efficiency here directly impacts operating costs and long-term sustainability.

2.7 Membrane Tank

The membrane tank is the core filtration stage of the MBR process, where suspended solids and microbial contaminants are purified in modules through physical separation. In these systems, the submerged membrane has a pore size of around 0.04 microns, which enables it to retain particulate matter, bacteria, and colloids, while allowing pure water, or permeate, to pass through.

A vital operational parameter during this stage is Transmembrane Pressure (TMP), which is the pressure difference across the membrane from the feed side to the permeate side. A low and stable TMP means filtration is going on efficiently, with minimal fouling. When there is a gradual rise in TMP over time, it means the membrane is getting clogged or undergoing fouling, and in this case, air scouring or chemical cleaning in place (CIP) is activated. Another essential parameter considered for this stage is the turbidity of the permeate, which practically shows the clarity of the permeate. One typical value for MBR systems to target is below 1 NTU to allow for safe reuse, but actual performance is discussed separately in later sections.

2.8 Permeate Storage Tank

Serving as a hydraulic buffer between treatment and reuse distribution, the permeate tank is a very essential for pH stabilization, chlorine residual retention, and flow adjustment for fluctuating demand. Monitoring pH in this tank prevents corrosion and promotes reuse compatibility, and keeping chlorine residuals prevents microbial regrowth. Since storage is prolonged, leaving the tank unmonitored can result in chlorine decay and degradation of water quality.

2.9 Centrifuge

The centrifuge dewaters excess sludge incoming from biological treatment and membrane separation, applying differential density by spinning the sludge to separate water from solids. Two metrics common in operation are cake dryness level of which affects disposal cost and ease of handling well as feed solids concentration latter having implications for throughput. Proper sludge removal keeps optimum levels of MLSS in the bioreactors and strikes a balance for the process. Additionally, a portion of the sludge separated from here is sent back to the biological modules for efficient reuse.

2.10 Disinfection

Disinfection after the purification process ensures microbiological safety prior to entering reuse phases. The dosage of sodium hypochlorite at this stage is typical to neutralise residual pathogens. Contact time, dose concentration, and residual chlorine concentration are crucial factors here. Disinfection is never complete if the residual is too low; if it is too high, then taste, odor, or corrosion concerns will arise in the reuse network.

3. Methodology and Data

3.1 Overview

The methodology of this research comprises of three interconnected streams: quantitative analysis of influent and effluent water quality, continuous monitoring of operational parameters at the plant, and qualitative field observations made during the site visit. The data collection through March 2025, during which the 6 MLD Membrane Bioreactor (MBR) sewage treatment plant in Palava City was functioning under regular loading conditions. The study relied on both primary and secondary data sources. Primary data were obtained through onsite inspections and discussions with operators about procedural workflows, safety practices, and plant automation, with full consent from plant operators.

The laboratory tests followed the methodological framework of the Central and State Pollution Control Boards and were carried out at the laboratory affiliated with the facility. Sampling of influent and effluent streams was done along with review of SCADA-logged continuous parameters to form a comprehensive understanding of plant performance and operational control. Observations were carefully recorded systematically at each unit process - collection, screening, biological treatment, membrane filtration, disinfection, and sludge management - to capture visible aspects such as color, odor, foaming, distribution of air, and evenness of flow. This information helped to provide a background for the interpretation of quantitative measurements and to confirm that the plant was functioning under normal conditions at the time of sampling.

To ensure clarity throughout the analysis, Tables 1 and 2 summarise and explain the key parameters referred to in this study. It includes the parameter, its unit of measurement, and a brief explanation of what its measuring.

Table 1. Water Quality Parameters

Parameter	**Unit of Measurement**	**What it measures**
BOD (Biochemical Oxygen Demand)	mg L^{-1}	The amount of oxygen required by microorganisms to decompose all organic matter; an indication of biodegradable and organic pollution
COD (Chemical Oxygen Demand)	mg L^{-1}	The amount of oxygen required to oxidize organic and inorganic substances; represents the overall contamination
TSS (Total Suspended Solids)	mg L^{-1}	The concentration of undissolved particles in water; indicates how clear the water is and its visual pollution level
TN/TKN (Total Nitrogen/Total Kjeldahl Nitrogen)	mg L^{-1}	It is the combined concentration of all forms of nitrogen: organic and ammonia; it assesses the nutrient content and how likely the water could

Parameter	**Unit of Measurement**	**What it measures**
		undergo eutrophication
Oil and Grease	mg L^{-1}	Measures the amount of hydrophobic organic compounds(fats) and can signify industrial and domestic contamination
pH	-	Measures acidity/alkalinity of the sample
Fecal Coliform	MPN $(100\ mL)^{-1}$	An indicator of bacteria that reside in the fecal matter of warm-blooded animals; used to assess the safety and effectiveness of disinfection methods
Turbidity	NTU (Nephelometric Turbidity Units)	How visually cloudy the water is, similar to an indirect measure of suspended particles concentration, also gives an idea of the performance of the physical filters

(Table on next page)

Table 2. Operational Parameters

Parameter	Unit of Measurement	What it measures
Transmembrane Pressure (TMP)	Bar or kPa	Measures the difference in pressure across the two sides of the membrane; gives an idea of how used/clogged the membrane is
Dissolved Oxygen (DO)	mg L^{-1} or PPM	Measures the oxygen available in the bioreactor; it is essential for efficient microbial activity
Sludge Retention Time (SRT)	hours	Measures the average time biomass remains in the bioreactor, indicating system stability.

3.2 Measuring Influent and Effluent Quality

Water quality of influent and effluent was determined through standard methods from the Indian Standards (IS) and from the Standard Methods for the Examination of Water and Wastewater (APHA 23rd edition, 2017). The samples were taken just before biological treatment (influent) and after chlorination (final effluent). All the samples were taken in clean, labeled containers, kept according to the specific method requirements, and taken to the laboratory within the designated holding times. Details regarding the formal procedure for each of the parameters are elaborated below.

The Biochemical Oxygen Demand (BOD) was measured according to IS 3025 (Part 38): 1989, where the five-day incubation at 20°C in airtight BOD bottles containing dilution water with known oxygen concentration was used. The Chemical Oxygen Demand (COD) was determined through the use of APHA 5220 B (23rd edition, 2017) using closed reflux and spectrophotometric detection after oxidation with dichromate. The quantity of Oil and Grease was evaluated using IS 3025 (Part 39): 1991 through solvent extraction and gravimetric determination after the extract had been evaporated. The pH of each sample was determined right after collection by the use of APHA 4500 H^+ B (23rd edition, 2017), with the electrode being calibrated daily against pH 4.0 and 7.0 buffers. Total Nitrogen was measured by the synergy of three APHA methods—4500 N_{org} B, 4500 NO_2 B, and 4500 NH_3 B (23rd edition, 2017)—to cover organic, nitrite, and ammonia fractions correspondingly.

Along with these primary chemical parameters, the laboratory testing also consisted of Total Suspended Solids (TSS) via IS 3025 (Part 17): 1984 and fecal coliform counting utilizing the membrane-filtration technique according to IS 1622: 1981. Each parameter was tested three times, and reagent blanks and duplicate samples were used to confirm the accuracy of the results. Instrumental readings were made using apparatuses like the Hach DR 3900 Spectrophotometer as well as calibrated digital pH meters. Daily calibration checks, recovery tests with standard solutions, and repeated cross-validation of results with reference samples ensured the quality throughout.

The laboratory analysis provided the data that determined the composition of influent and effluent, and these were then compared with the standards of the Environment (Protection) Rules 1986, Schedule VI, and with internal guidelines which the facility had adopted.

3.3 Monitoring of Plant Operations

The laboratory data were supplemented by checking the plant's operational parameters continuously through the Supervisory Control and Data Acquisition (SCADA) system and parallel comparison with field sightings. The parameters tracked included the flow rate, dissolved oxygen, the transmembrane pressure (TMP) within the MBR modules, and pH in the permeate storage tank.

The standard operating procedure (SOP) was followed while checking the operational parameters, and it laid down the steps to take in case of a deviation from the set limits. Monitoring indicated that the water levels in the collection tanks were to be kept between 20% and 70% of the capacity, and the equalization tanks were to be in the hydraulic buffering area of 40% and 80% operating range, whereas the bioreactor dissolved oxygen was to be controlled through automatic blower adjusting, going from 1.5 to 2.5 ppm and keeping the specific-air demand (SV-30) at 700–900 mL/L. The transmembrane pressure was not to exceed 0.40 bars so that fouling does not take place, and one blower at least for every MBR tank runs all the time to facilitate airing.

A continuous flow of chlorine is maintained in the treated water by controlling the dose of sodium hypochlorite. The residual sludge from the bioreactor is cleared to prevent biomass from getting too old and to keep the culture healthy, but some portions of it are reused and returned to the biological modules. Additionally, membranes undergo chemical cleaning thrice a week, with sodium hypochlorite or acetate and citric acid, which are used to tackle organic and inorganic deposits, respectively.

This was a nondisruptive study since visual observations were made every round of monitoring. Among other checks, the operators were able to confirm that uniform bubble distribution was produced by the air diffusers in the aeration tanks, the darkness of the sludge in the anoxic tank was observed, the earthiness of the odor sampled from there was, too, and no foaming, scum accumulation, or abnormal vibration disturbances were observed or reported in the case of blowers or pumps. Moreover, at the membrane gallery, the schedule of air-scour bursts and TMP readings was compared with the SOP limits to detect early signs of fouling. The permeate tank and disinfection chamber inspection included checks for clarity, presence of chlorine smell, and no biofilm growth, while consistency of centrifuge cake and uniformity of polymer feed were the main checks in the centrifuge area. These observations, being qualitative for the most part, simply supported the quantitative dataset and also confirmed that stable and representative operating conditions existed during the drawing of samples, hence the sampling was accurate.

3.4 Ethical and Safety Concerns

The entire data collection process was carried out in close collaboration with the facility's operations team under strict observance of safety norms. Personal protective equipment, such as helmets, gloves, goggles, safety shoes, and respirators, was used throughout the operation in line with the site's PPE policy. Access to confined spaces was not permitted without the clearance of authorized personnel, and after proper ventilation was confirmed. The research was observational and non-invasive; it did not alter the functioning of the plant or introduce any external substances into the process.

3.5 Limitations

The data-collection process had certain limitations. While SCADA access for continuous monitoring was available, it was limited to exports and not real-time feeds, thus making it difficult to capture short-term activity. Some parameters, like the specific design of the membrane module, cleaning-solution composition, and dosing-control algorithms, were not disclosed for confidentiality purposes. Despite these limitations, the multi-layered dataset consisting of laboratory, SCADA, and observational information offers a solid basis for the performance evaluation to be presented in the subsequent section.

4. Data Analysis

4.1 Analytical Overview

This part provides a detailed interpretation of the quantitative and operational data collected by means of laboratory tests, SCADA monitoring, and on-the-spot observations to evaluate the performance of the 6 MLD Membrane Bioreactor (MBR) sewage treatment plant. The analysis is directed towards two major aspects: the pollutant removal that resulted in the treatment efficiency, and the operational parameters that were reliable and consistent enough to support long-term stability.

Data from all recorded measurements were merged into one dataset, converted to uniform units, and checked against maintenance logs. The quality of influent and effluent was assessed with reference to the allowable limits set by the Maharashtra Pollution Control. Simultaneously, the assessment of operational data like transmembrane pressure (TMP), dissolved oxygen (DO), turbidity, and residual chlorine was conducted.

The next sections will unfold this analysis in a sequence, starting with the quality of water coming in and going out (4.2), then coming to the parameters used for the process (4.3), going further to inter-parameter correlations (4.4), discussing water and power balance (4.5), and finally putting down a summary of findings (4.6).

4.2 Influent and Effluent Data

The quality of influent water was analysed to set standards before entering the treatment plant. The values given below in Table 3 reflect the typical pollutant load from domestic sources within Palava City Sector 2.

(Table on next page)

Table 3. Influent water quality

Parameter	Unit	Inlet Actual
BOD	mg L^{-1}	36
COD	mg L^{-1}	126
TSS	mg L^{-1}	31
TN/TKN	mg L^{-1}	1.1
Oil and Grease	mg L^{-1}	1.03
Fecal Coliform	MPN $(100ml)^{-1}$	-
Turbidity	NTU	-
pH	-	6.96

The influent quality is typically influenced by the combination of untreated household sewage and the greywater from the residential towers and the surrounding facilities. The BOD value of 36 mg L^{-1} and the COD value of 126 mg L^{-1} measured in the influent are typical of domestic wastewater with moderate loading. They match the profiles of municipal influent in mixed-use townships. The TSS level of 26 mg L^{-1} suggests that a considerable amount of solid matter is part of the influent and will be exposed to the treatment process, and thus, it is critical for the pretreatment (mechanical screening and equalization) to keep the membrane modules that are operating downstream safe. The Total Nitrogen (1.1 mg L^{-1}) and Oil and Grease (1.03 mg L^{-1}) figures indicate very low levels of nutrient and hydrocarbon pollution or contamination, thus showing us that the influent is mainly composed of residential discharges, not mixed with large commercial or industrial discharges. This is consistent with the source being a residential complex.

At the influent stage, no tests for Fecal Coliform have been done. Raw sewage commonly contains bacteria in high concentrations, and working with samples that are so heavily contaminated in the lab is a safety risk. Furthermore, the analytical aim is the assessment of the disinfection performance; hence, post-treatment fecal coliform testing (in the effluent) is more applicable. Turbidity was not determined in the influent either because raw sewage is usually not transparent and has a considerable amount of suspended solids. Therefore, the turbidity measurements would be redundant. The real turbidity measurement becomes important in determining the quality of the final effluent that has passed through membrane filtration.

Moving on to the final effluent, it was compared against two sets of standards- one set by the Central and Maharashtra Pollution Control Boards, and the stricter internal standards set by the plant operators. These limits ensure that the effluent complies with regulatory discharge quality, but also exceeds those standards to ensure safety within Palava City. Table 4 shows these values.

Table 4. Effluent water quality compared to standards

Parameter	**Unit**	**Outlet standards(Pollution Control Board)**	**Outlet standards(Internally set)**	**Outlet Actual**
BOD	mg L^{-1}	<30	<30	<1.0
COD	mg L^{-1}	<30	<30	17
TSS	mg L^{-1}	<100	<5	3
TN/TKN	mg L^{-1}	<15	<10	<1.0

Oil and Grease	mg L^{-1}	<5	<5	<1.0
Fecal Coliform	MPN $(100ml)^{-1}$	None	None	Not Detected
Turbidity	NTU	-	<1	<1
pH	-	6.5-9	6.5-7.5	7.21

The effluent BOD value of less than 1 mg L^{-1} demonstrates almost complete removal of all biodegradable organic matter. Taking into consideration the influent BOD of 36 mg L^{-1}, the plant has achieved over a 97% reduction in BOD. The value of 1 mg L^{-1} is well below the limits set both by the Pollution Control Board and by the internal standards. These results show that the aerobic breakdown in the bioreactor and the membrane filter function optimally, leaving negligible organic matter.

The COD values of 17 mg L^{-1} also lie below the 30 mg L^{-1} limit, reflecting the high efficiency of the oxidative portion of the reactor. Since the COD values account for both biodegradable and non-biodegradable matter, and the fact that BOD values have significantly decreased, the low COD values also show that the effluent water is significantly ‘cleaner’ than the inlet water.

Similarly, the TSS value measured at 3 mg L^{-1} is much lower than the limits set by the PCB, and even exceeds the much stricter internal limit of <5 mg L^{-1}. This shows how both the mechanical filtration(the screens and filters) and the membrane filter effectively remove the majority of the suspending solids and colloids, producing a cleaner effluent. This is reflected in the turbidity of the water measured at <1.0 NTU, meeting the standards and displaying high clarity, indicating high-quality filtration.

Total Nitrogen values of <1.0 mg L^{-1} demonstrate effective nutrient removal across both the biological and mechanical processes of the plant, exceeding both the PCB(<15 mg L^{-1}) and the internal(<10 mg L^{-1}) limits. As this plant's output is connected to non-potable uses, ensuring minimal nitrogen in the effluent is essential to minimize the risk of eutrophication. This plant ensures the same.

Oil and grease values indicate levels less than 1 mg L^{-1}, showing the effectiveness of the screening and oxidation processes that occur to filter out/remove lipid inputs. Fecal coliform counts were also not detected in the final effluent, confirming complete disinfection. This is possible due to the ultrafiltration process that occurs in the membrane, paired with sodium hypochlorite disinfection, which eliminates all pathogens present. This step confirms the reliability of the plant's final processes to guarantee safe reuse. The measured pH of 7.21 lies within both the PCB and internally set limits, and is very close to a neutral pH of 7, implying that all the processes in the plant output chemical neutral water without over-acidifying or over-alkalizing the water.

All of these parameters together demonstrate that the effluent water meets but also exceeds all standards set. The consistency of the parameters across both internal and PCB standards demonstrates stable processes and reliability: something essential within a residential area.

4.3 Operational Parameters

To ensure the proper functioning and the long-term health of the system, it is very important to keep the critical process parameters in the optimal range. Among all the parameters, the most important ones are the dissolved oxygen (DO) in the bioreactor, transmembrane pressure (TMP) across the membrane modules, and sludge retention time (SRT). They are the most important indicators of biological activity, membrane performance, and the general process balance of the MBR. The ongoing monitoring of these parameters via the SCADA system of the plant allows the operating staff to maintain a good treatment efficiency with minimum fouling and energy usage.

The parameters measured during the study period are presented in Table 5 below, which shows the target control ranges indicated in the Standard Operating Procedure as well as the observed values obtained from daily plant records. These parameters as a whole give an idea about the internal condition of the MBR process, its potential to strike the right balance between biological degradation, filtration, and sludge management.

Table 5. Operational Parameters

Parameter	Unit	Control Range	Actual
Dissolved Oxygen (DO)	ppm	1.5-2.5	1.9
Transmembrane Pressure (TMP)	bar or kPa	<-0.30	-0.40
Sludge Retention Time (SRT)	hours	Varies on the plant	7-8

The dissolved oxygen in the aeration tank is kept within the limits of 1.5 and 2.5 mg L^{-1} according to the plant's Standard Operating Procedures. The value of 2.1 mg L^{-1} is indicative of balanced oxygen transfer. DO in this range is beneficial for BOD and COD reduction by keeping the bacterial population healthy.

TMP is the direct pressure difference measured across the ultrafiltration membranes and is an indicator of membrane fouling. The SOP specifies –0.30 bar as the upper limit for suction; however, the value of

–0.40 bar was noticed, indicating that the resistance to flow is slightly higher. This usually arises from a gradual buildup and shows that chemical cleaning (CIP) may be required soon to bring back the TMP within limits.

SRT is the time that the biomass remains in the bioreactor on average, helping balance between sludge age, microbial composition, and overall stability. Even though there are no universal standards in the field, the plant personnel keep the SRT at 7-8 hours, which they consider to be the best for the system. This retention time is enough for the growth of bacteria needed for organic oxidation, but does not allow for the accumulation of solids that may cause stress on the membranes or upset other parameters.

4.4 Summary of Results

The comprehensive study involving the influent, effluent, and operational parameters indicates that the MBR sewage treatment plant not only complies with the regulatory quality standards but also with the internal ones consistently. The system reached almost total elimination of organic matter, with the levels of BOD and COD far less than the limits set, while the clarity of the effluent remained below 1 NTU, and fecal coliforms were not detected at all. The dissolved oxygen, transmembrane pressure, and sludge retention time, which are the operational measures, were kept either within the optimal control bands or very close to those, showing that biological activity and membrane filtration are working effectively. The only minor deviation detected was the TMP that was slightly higher than normal (–0.40 bar), which is indicative of membrane fouling, which is normal. However, the membrane should be and likely will be cleaned soon. Hence, this plant is seen to possess very high treatment efficiency, stable processes, and continuous non-potable reuse within the city of Palava.

5. Challenges and Insights

The sewage treatment plant, although showcasing great treatment efficiency and operational stability, still revealed a number of challenges and areas for improvement during its study period. The insights obtained through the data, discussions with the operators, and on-site observation of the plant emphasize the need for continuous optimization and documentation for the long run in performance.

The issue of membrane fouling was the most stubborn operational problem that could be observed; this was apparent from the gradual rises in transmembrane pressure over and above the recommended limit of –0.30 bar. Membrane fouling in MBR systems, which is a natural process, occurs due to the build-up of solids, microbial flocs, and colloidal matter on the membrane surface. The plant's scheduled cleaning alternating between sodium-hypochlorite and citric-acid solutions has been effective in restoring permeability; however, optimizing cleaning frequency is still very important to cut down both chemical use and membrane fatigue. The consistent maintenance of equalization and pre-screening efficiency is also a preventive measure that helps in controlling fouling rates.

Aeration management is an issue that also deserves attention. The oxygen of the water must be kept between 1.5 and 2.5 mg L^{-1} which is the range for biological oxidation and energy efficiency. Blower wear, calibration drift, or temporary loading variations may sometimes cause occasional fluctuations. Although these deviations were short-lived, the automated DO control system is very dependent on sensor accuracy; therefore, regular calibration and preventive maintenance are essential to avoid excessive energy consumption during the oxygen transfer process while still being able to maintain it.

Energy data for the entire plant is also monitored through the SCADA system. However, this study has chosen not to incorporate this data. The choice to exclude it was made in order to keep the study focused on treatment efficiency and water quality parameters instead of energy benchmarking based on operation.

A combination of power consumption data in future studies could yield a clearer plant's overall efficiency and cost-effectiveness, particularly for long-term optimization.

Moreover, it is worth mentioning that a number of difficulties faced in data collection were recognized and taken into consideration in the analysis. These problems have been addressed in Section 3.

6. Conclusion

This study provided an assessment of the operation and performance of a sewage treatment plant using a 6 MLD Membrane Bioreactor (MBR) located at Palava City, Maharashtra. The plant is capable of treating domestic wastewater to be reused as non-potable water in the township without any further treatment. The research involved laboratory analyses, SCADA-monitored operational data as well and field observations.

The removal of organic and suspended solids through the MBR system was extremely effective, and the levels of BOD, COD, and TSS were significantly below both PCB and internal operational limits. The disinfection process was able to eliminate the bacteria and particles to an extent that fecal coliform was not detected, and pH and turbidity were optimal for safe reuse. Such results provide proof of the reliability of MBR technology in obtaining a consistent effluent quality.

The monitoring of operational parameters like dissolved oxygen, transmembrane pressure, and sludge retention time showed stable biological and filtration performance throughout the observation period. The plant kept the aerobic activity within the most favorable limits of DO, and although the TMP at one point exceeded the most favorable range, such variations were not only manageable but also quickly rectified through the routine cleaning and maintenance.

To summarize, the 6 MLD MBR in Palava City is characterized by a high level of treatment efficacy and strong operational resilience. The study affirms that MBR systems represent an advanced and sustainable solution for treating domestic wastewater. Their compact designs, high effluent quality, and potential for water reuse post-treatment make them well-suited for an urban context where land may be restricted. As cities expand, MBR-based treatment systems housed under the domestic complex may be an effective solution, as these systems play essential roles in achieving circular water management and ensuring sustainability in the years ahead.

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