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Article

Study of waste management treatment facilities using advanced Membrane Bio Reactor (MBR) technology

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Abstract: Sewage treatment plays a crucial role in sustainable urban and industrial development. This study focuses on the generation and treatment of sewage from residential, institutional, commercial, and industrial sources, distinguishing between grey water and black water. While grey water is relatively easier to treat, conventional practices in India merge both streams for processing. This research evaluates the application of advanced Membrane Bio Reactor (MBR) technology in a Sewage Treatment Plant (STP) at an industrial township in Andhra Pradesh, India, to achieve Zero Liquid Discharge (ZLD). The study demonstrates the significant efficiency of MBR technology in removing contaminants, with Biochemical Oxygen Demand (BOD) reduced from 350 mg/L to 20 mg/L, Chemical Oxygen Demand (COD) from 650 mg/L to 50 mg/L, and Total Suspended Solids (TSS) from 150 mg/L to 4 mg/L. Additionally, oil and grease levels decreased from 19 mg/L to 4 mg/L, and total nitrogen dropped from 45 mg/L to 10 mg/L. These results affirm the effectiveness of MBR in producing high-quality treated water suitable for irrigation and toilet flushing. The research involved systematic sampling of influent and effluent wastewater over a set period, employing analytical methods like spectrophotometry and chromatography. Key operational parameters such as flux rate, transmembrane pressure (TMP), sludge retention time (SRT), and hydraulic retention time (HRT) were monitored to optimize efficiency. Comparative analysis with conventional treatment methods highlights MBR's advantages, including superior pollutant removal, reduced footprint, and lower energy consumption. Real-time sensors and lab-scale MBR setups were used for continuous data collection and statistical analysis, confirming MBR's effectiveness in sustainable wastewater treatment.

Keywords: sewage treatment; Membrane Bioreactor (MBR); Zero Liquid Discharge (ZLD); wastewater management; pollutant removal; industrial wastewater; water reuse; sustainable treatment technologies

1. Introduction

To effectively select a treatment technology, it is crucial first to understand the properties of wastewater. Characteristics such as pH, organic load, nutrient content, and presence of heavy metals determine the most suitable treatment approach. For example, high organic content may require biological treatment, while toxic contaminants necessitate chemical or advanced oxidation methods. Once these properties are analyzed, treatment technologies can be matched accordingly as primary treatment for solids removal, secondary for biological degradation, and tertiary for advanced purification. This systematic transition ensures that each stage effectively addresses specific wastewater characteristics, optimizing overall treatment efficiency and compliance with environmental regulations. This paper aims to outline the design and implementation methodology for installing a sewage network and Sewage Treatment Plant (STP) at an industrial township in Andhra Pradesh. This paper addresses the selection of an appropriate STP technology that meets the specific needs of the industrial township, details the process flow, and provides information on technical specifications, equipment, system packages, execution strategy, and operational requirements for the successful operation of the sewage treatment facility [1]. It offers a comprehensive technical report on the project, which will serve as a guideline for its implementation and future operation. The paper also includes the operational methodology and project cost estimates. A clear understanding of wastewater properties is vital for the design and operation of collection, treatment, and disposal systems, as well as for the overall management of environmental quality. To enhance this understanding, key parameters of wastewater are mentioned below in **Figure 1**:

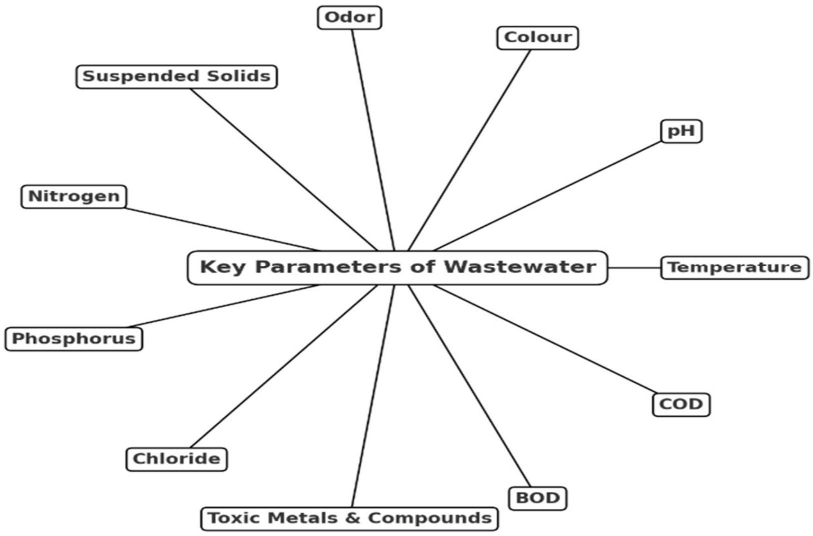

Figure 1. Key parameters of wastewater.

Wastewater contains all the dissolved minerals from the freshwater used, as well as various contaminants, including proteins, carbohydrates, oils, and fats. These contaminants are biodegradable and consume oxygen during the degradation process. Consequently, they are quantified in terms of their oxygen demand, which can be measured through laboratory tests. This is referred to as Biological Oxygen Demand (BOD). Additionally, certain chemicals that contaminate water during domestic use also consume oxygen, and their demand is measured through a test known as Chemical Oxygen Demand (COD).

Typically, domestic sewage would contain approximately 300 to 450 mg/liter of BOD and 450 to 500 mg/liter of COD. Sewage also contains coliform bacteria (E.coli), which is harmful to human beings [2]. Another parameter of sewage is the high level of Total Suspended Solids (TSS). The presence of high levels of TSS constituents turns the sewage black in color. Sewage in septic tanks also has a strong, unpleasant odor. Membrane Bioreactors (MBRs) integrate the principles of the Activated Sludge Process with membrane filtration technology [3]. This system efficiently addresses challenges associated with industrial wastewater and heavy metal contamination [4].

According to Jiang et al. [5] membrane rupture led to an intensified peak at 280/335 nm. MBRs demonstrated higher efficiency in virus removal compared to conventional activated sludge treatment [6]. Mofatto et al. [7] reported that 78% of biological sludge was generated at a hydraulic retention time (HRT) of six hours. The ultrafiltration membranes and the formation of a cake layer in MBRs enhance retention performance [8]. Additionally, MBRs exhibited twice the efficiency of conventional activated sludge (CAS) in minimizing the transfer of environmental antibiotic resistance genes (eARGs) from sludge to effluent [9]. The effluent's nutrient concentration was successfully lowered to permissible levels, with nitrogenous compounds and phosphate concentrations maintained at < 30 mg/L and ≤ 5 mg/L, respectively, in compliance with WHO standards for wastewater reuse in irrigation [10]. Furthermore, PAC-MBR technology improved organic matter removal efficiency from 88.6% ± 2.9% to 96.0% ± 1.2% [11].

Sewage treatment is the process of eliminating contaminants from municipal wastewater using physical, chemical, and biological methods. The treated water, also known as effluent, is rendered safe for reuse [12]. During the sewage treatment process, a semi-solid byproduct, known as sewage sludge, is generated. This sludge requires additional processing before it can be safely disposed of or applied to land. Sewage is typically conveyed to treatment plants through a network of pipes, utilizing gravity and pumps to assist in the flow [13]. In areas where the terrain is uneven, sewage may need to be lifted by sewage pumps before being directed to the treatment facility. The initial phase of sewage filtration usually involves a bar screen that filters out large solids and debris, which are then collected in dumpsters and sent to landfills. Oil and grease are also removed before the primary treatment stage. Sewage collection and treatment in India are regulated by local, state, and central authorities, with specific standards and guidelines to follow. Sewage treatment typically occurs in three stages: primary, secondary, and tertiary treatment.

The byproduct that accumulates during sewage treatment is known as sludge (or biosolids). The treatment and disposal of sewage sludge play a critical role in the design and functioning of wastewater treatment plants. The primary objectives of sludge treatment are to minimize its volume and stabilize organic materials [14]. Stabilized sludge is odorless and can be handled safely without causing health risks or nuisances. Reducing sludge volume lowers the costs associated with pumping and storage. The process of sludge treatment and disposal typically involves methods such as:

1) Anaerobic digestion
2) Aerobic digestion
3) Composting
4) Incineration
5) Sludge disposal
6) Sludge dewatering
7) Sludge drying

These processes are essential in managing and mitigating the environmental impact of sewage sludge after treatment. The typical process flow chart of STP is defined in **Figure 2**.

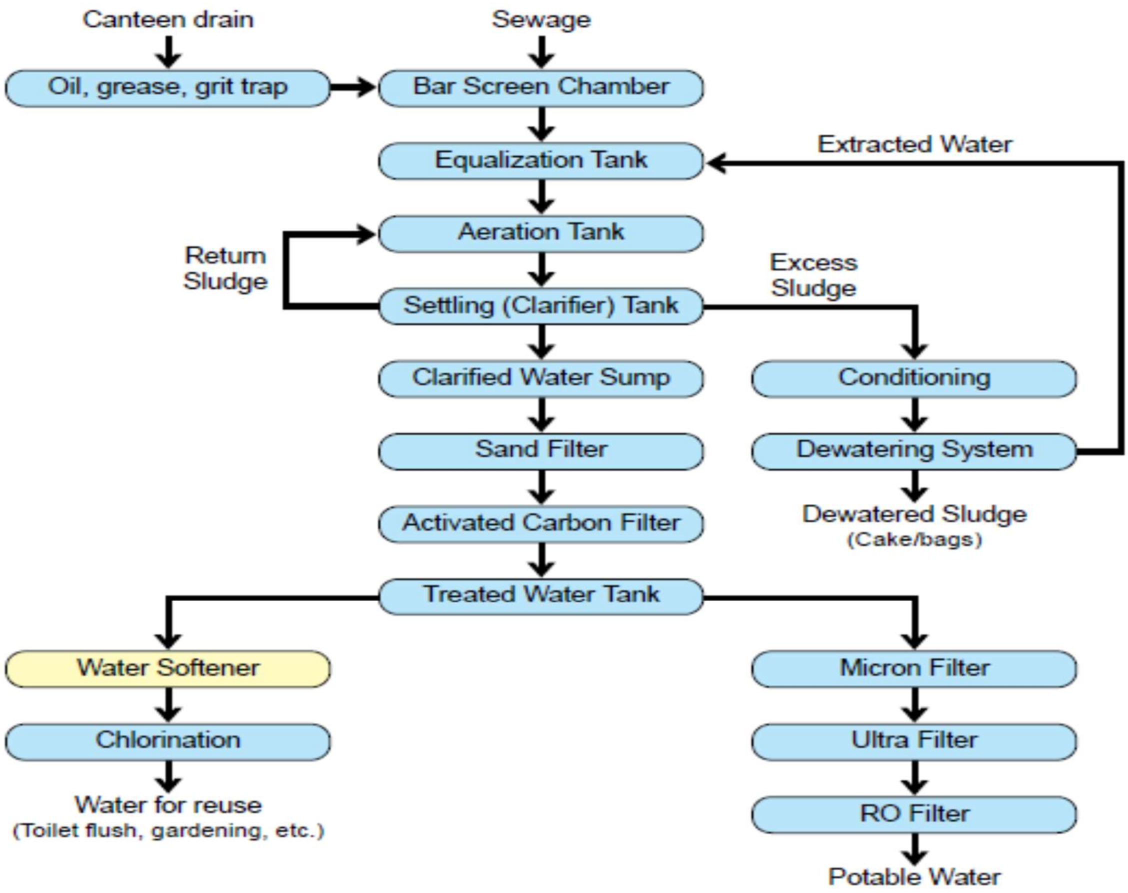

Figure 2. Typical process flow chart of STP.

The concept is straightforward, as microorganisms transform a substantial amount of contaminated water into clean water. This process also generates a byproduct, a significantly reduced and compact solid biomass. Nevertheless, converting this basic idea into an efficiently designed and engineered Sewage Treatment Plant (STP) presents a considerable challenge[15]. It necessitates a thorough understanding of microbiology, as well as chemical and mechanical engineering principles. A Sewage Treatment Plant (STP) is designed with key factors in mind to ensure consistent and reliable performance while complying with guidelines set by the Ministry of Environment, Forest and Climate Change (MoEF & CC) and local pollution control board regulations. It should be durable, with a lifespan of at least 10–15 years without major repairs, while minimizing capital investment, energy consumption, and chemical usage to meet required water quality standards. Additionally, the design should prioritize simplicity in operation and maintenance. There are various options for handling sewage sludge. Several factors impact the selection of the appropriate method, including the scale of the waste treatment facility generating the sludge and the physical and chemical characteristics of the sludge. These processes include preliminary sludge treatment (such as densification, conditioning, and final dewatering), thermal and biological treatments, and the ultimate disposal or treatment of the sludge [16]. The main advantages of an STP include reliable water availability for secondary uses, significant reductions in freshwater consumption, decreased environmental impact, and better public health

[17]. To determine the most suitable technology, various sewage treatment options and STP technologies have been evaluated, including:

1) Activated Sludge Process (ASP)
2) Upflow Anaerobic Sludge Blanket Reactor (UASB)
3) Sequential Batch Reactor (SBR) process
4) Decentralized Water Treatment System (DEWATS)
5) Reed Bed Sewage Treatment System
6) Moving Bed Biofilm Reactor (MBBR)
7) Membrane Bio Reactor (MBR)

2. Materials and methods

Water demand is calculated based on the guidelines and standards laid down by the Central Public Health Environmental and Engineering Organization (CPHEEO) and the National Building Code (NBC). The total quantity of water required for the existing "B" type (Hostel) and "C" type (Residential quarters) of the industrial township and protection staff township, considering a total population of 500 no's (refer to **Figure 3**), is estimated to be about 65 KLD, considering a miscellaneous and floating population of about 102 numbers in total. The sewage generated during the operation phase will be subjected to tertiary treatment in STP [18]. The entire (100%) treated water will be used for landscaping in the township site, and excess treated water will be used for avenue plantation. It is proposed to install an STP of 65 KLD capacity to treat the sewage generated from industrial townships [19].

Figure 3. Satellite imagery of the location of soak pits of STP for the industrial township regarding C and B blocks.

Considering the advantages and disadvantages of STP technologies, the latest MBR technology with the high-performance membrane module for the MBR reactor is planned to be adopted [20]. MBR technology has proven to be superior to others and can handle pH variation, shock loading, cold temperature, and drastically reduce plant size. The MBR module has been proven to stabilize most wastewater plants and is used on a global scale with great success.

Considering the above-arrived sewage quantity, state-of-the-art Membrane Bio Reactor (MBR) technology of STP with a capacity of 65 KLD is envisaged to be adopted for industrial townships. MBR is the combination of a membrane process like microfiltration or ultrafiltration with a biological treatment and Activated Sludge Process [21]. The proposed STP is planned to be of modular type with a plan to increase the size in the future as per demand. The treatment process consists of four stages and is given below:

Stage 1: Primary treatment (prescreen chamber, oil and grease removal tank, equalization tank, and fine screen).

Stage 2: Secondary or biological treatment (inlet chamber, aeration tank, anoxic tank, and Membrane Bio Reactor (MBR)).

The MLSS from the aeration tank will overflow into the membrane tank, and sludge from the MBR tank will be recycled back into an anoxic tank to maintain MLSS within the biological system [22]. The MBR modules have cassettes in the MBR tank. Self-priming centrifugal pumps are used for the suction of permeate from the MBR module at a constant flow rate and pressure [23]. The MBR system will be incorporated with a continuous air scouring and intermittent backwash system, which will reduce membrane surface fouling. The cleaning-in-place (CIP) process system, which is a method used to clean equipment without disassembly, will be implemented. It is intended for enhanced maintenance cleaning/recovery, which suggests that it will improve the cleaning process, ensuring better performance and longevity of the system. The system will also be used for cleaning membranes with higher chemical concentrations, indicating that stronger cleaning solutions will be applied to remove fouling, scaling, or contaminants from membranes (likely used in filtration processes like reverse osmosis or ultrafiltration).

Due to the small pore sizes, the membrane is not only a barrier for the activated sludge but also for suspended substances, bacteria, and viruses [24]. Permeate generated from MBR is free from suspended solids, bacteria, and viruses and delivers high-quality treated water. The arrangement of MBR membranes in MBR modules is defined in **Figure 4**.

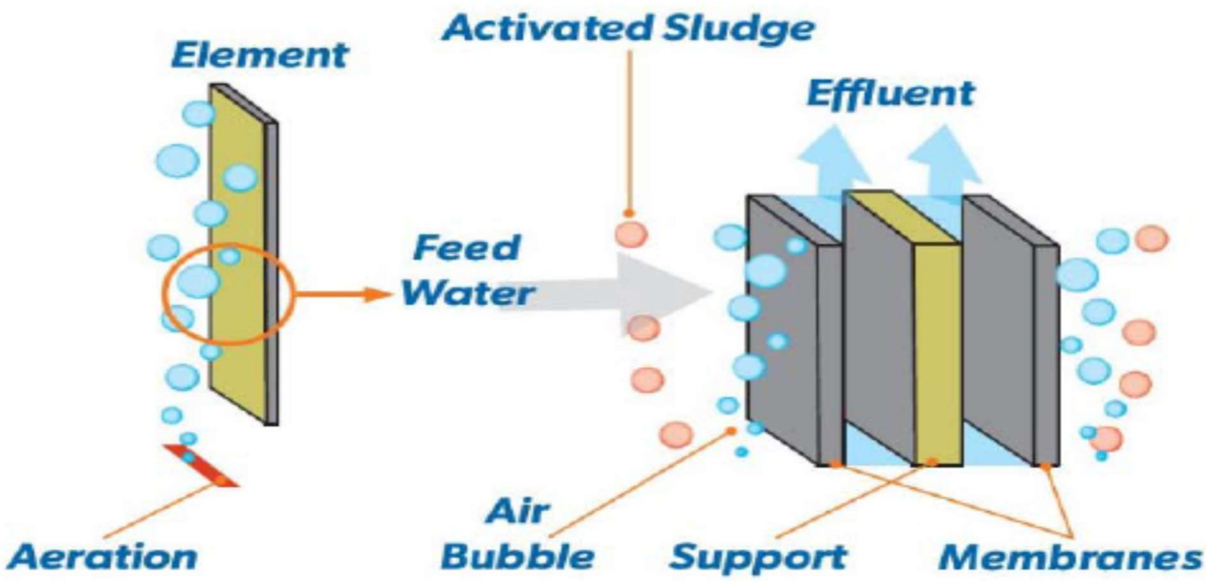

Figure 4. Arrangement of MBR membranes in MBR modules.

The flat sheet MBR membranes are submerged in an MBR tank and will be operated in cyclic mode, which includes filtration and relaxation followed by backwash. The aeration device installed under the membrane modules guarantees the necessary air supply to keep biomass in suspension [25]. This upstream airflow will permanently pass through the membrane module and will relieve the fouling of the membrane surface. Thus, intermittent backwash and continuous air scouring remove the fouling/deposit material from the membrane surface to achieve a constant higher flux [26]. The self-priming centrifugal pumps are planned to be provided for the suction of permeate from the MBR module, and sludge recirculation pumps will recycle the concentrated MLSS back to the anoxic tank. The typical arrangement of MBR modules in the MBR tank is shown in **Figure 5**.

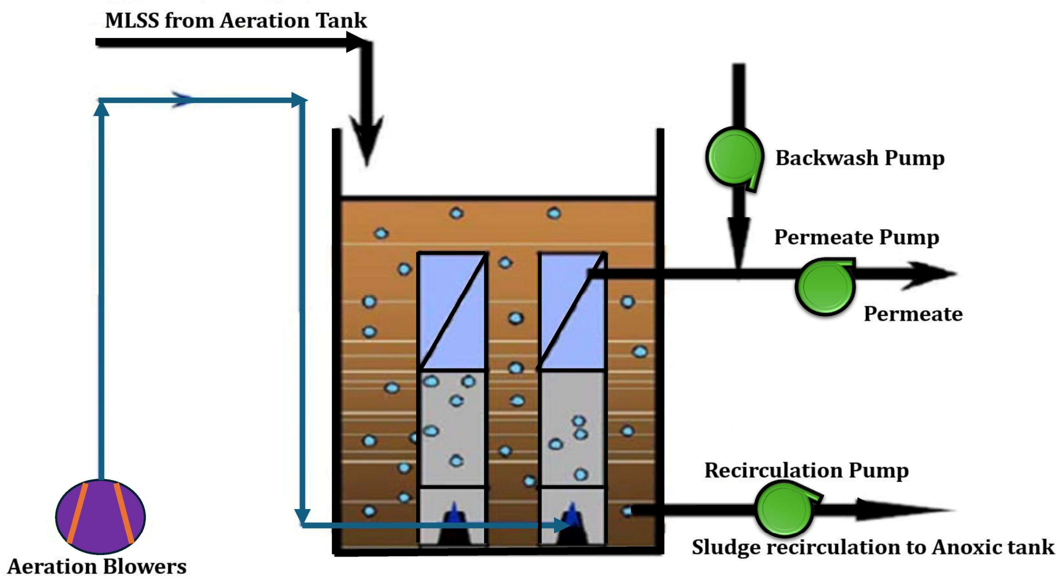

Figure 5. Arrangement of MBR modules in MBR tank.

Maintenance and cleaning of Membrane Bio Reactor (MBR) systems are crucial for ensuring long-term efficiency and operational reliability. Typically, routine maintenance, including membrane backwashing and chemical cleaning, is required every 3 to 6 months, depending on influent characteristics and membrane fouling rates. A more intensive clean-in-place (CIP) process may be needed annually or biannually. Operational costs primarily include energy consumption for aeration, chemical cleaning agents, and membrane replacement, with membrane lifespan ranging from 5 to 10 years. While MBR systems have higher initial costs compared to conventional treatment methods, they offer lower sludge handling costs and reduced tertiary treatment requirements. Proper maintenance strategies, such as optimizing aeration rates and periodic chemical cleaning, help sustain membrane performance, minimizing long-term expenses and operational disruptions. Membrane Bio Reactor (MBR) systems typically operate at flux rates ranging from 10 to 30 LMH (liters per square meter per hour), depending on influent quality and process optimization. Maintaining system efficiency over time requires strict control of operational parameters, including aeration rates, backwash cycles, and chemical cleaning protocols to mitigate fouling.

Additionally, managing mixed liquor suspended solids (MLSS) concentrations, sludge retention time (SRT), and hydraulic retention time (HRT) is critical for sustaining long-term performance and ensuring the overall viability of the treatment process. Backwash and relaxation cycles in Membrane Bio Reactor (MBR) systems for townships typically occur every 30–60 min to mitigate fouling. These cycles are fully automated and controlled by a programmable logic controller (PLC), which monitors membrane pressures and flux rates. Operators can adjust the backwash frequency or duration of performance indicators, such as transmembrane pressure or permeate flow, to deviate from normal ranges. Real-time data collection ensures prompt detection of fouling trends, enabling timely interventions to preserve membrane efficiency and extend operational lifespan. MBR systems for townships typically generate lower sludge volumes compared to conventional Activated Sludge Processes, thanks to extended sludge retention times. This results in more stabilized sludge with reduced frequency of disposal. A common dewatering technology is the decanter centrifuge, which can handle feed rates suited to the plant’s capacity (e.g., up to 2–5 m^3/h for small to medium township STPs) and typically achieves cake dryness in the range of 18%–25% total solids, depending on polymer dosage and feed characteristics. Alternative options, such as belt filter presses or plate-and-frame filter presses, may be employed based on on-site constraints, local regulations, and lifecycle cost considerations.

A de-venting device (bubble trap) is also integrated into the filtration line to remove entrapped air from the permeate line [27]. The de-venting device will be installed at the highest elevation to ensure complete de-venting of the permeate line, e.g., during the relaxation cycle. After every 24 h. of the cycle, de-venting of the MBR system will be done to remove the air trap from the permeate line [28]. During the de-venting cycle, the permeate pump is stopped, and the permeate suction auto valve is closed. Then the backwash pump starts, the backwash auto valve is opened, and the de-venting valve is kept open. Backwash flow removes all air trapped in the permeate line via a bubble trap and de-venting valve [29]. The load of the MBR module for civil foundation design is approx. 450 kg.

The process treatment scheme of the 65 KLD MBR-based STP system is shown in **Figure 6**. During filtration, self-priming centrifugal pumps are used for the suction of permeate from the MBR module [30]. The pump also maintains the constant pressure and flow rate of permeate as per design conditions. After the filtration cycle, the MBR permeate pump will stop, and the system will enter relaxation mode, i.e., no permeation will happen. During relaxation, filtration stops, but air scouring is continuous, which removes activated sludge deposits from the membrane surface [31]. After the relaxation cycle, the MBR system enters a backwash cycle where the membranes are backwashed by permeate water through a backwash pump. Generally, the maximum backwash pressure will be limited to 1.5 to 2 bars. During the filtration/permeation cycle, the activated sludge present outside the membrane forms a layer over the MBR membrane, which reduces the performance of the membrane or increases the Trans Membrane Pressure (TMP). The fouling/deposits of membranes are removed during backwashing by applying positive pressure on the permeate side, i.e., in reverse flow through the membrane layer [32]. The cyclic operation of MBR is fully automated by PLC, which will minimize operator intervention. The backwash tank is always filled with permeate water to ensure that backwash water is always available during MBR operation.

Stage 3: Tertiary treatment (filter feed tank, UV sterilizer).

Stage 4: Sludge treatment (decanter centrifuge).

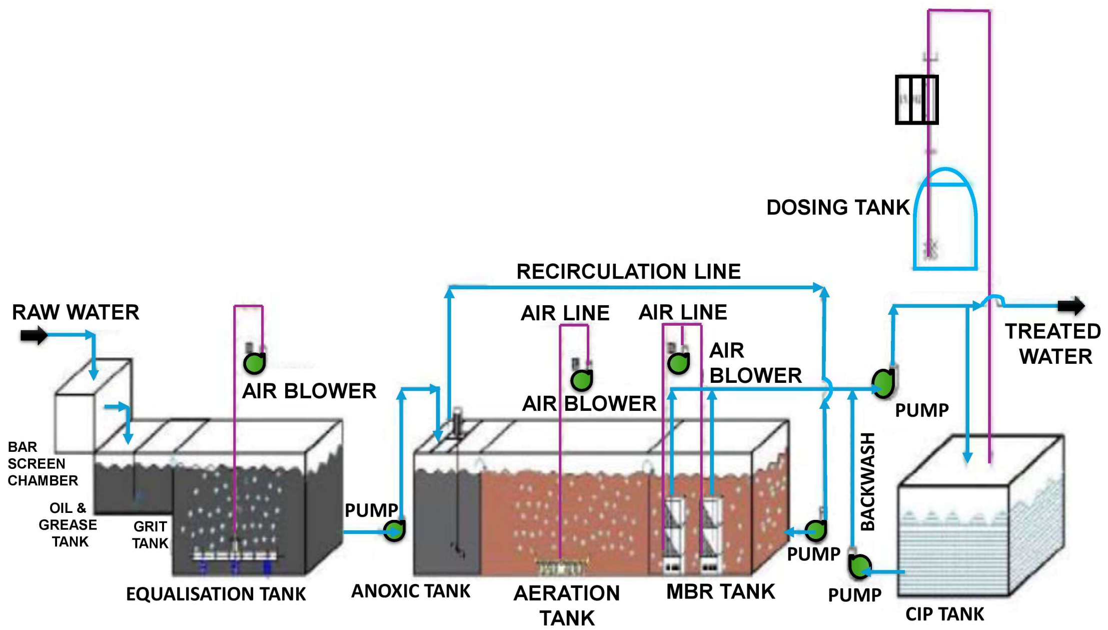

Figure 6. Process treatment scheme of 65 KLD MBR-based STP system.

3. Results and discussions

MBR systems can reduce the required footprint by 40%–60% compared to conventional Activated Sludge Processes, primarily due to the elimination of secondary clarifiers and more compact bioreactor configurations. Sludge production is often 30%–40% lower, owing to higher mixed liquor suspended solids (MLSS) concentrations and extended sludge retention times. In the 65 KLD MBR plant at the township, the footprint decreased from approximately 325 m^2 to 350 m^2, while sludge disposal frequency was reduced by nearly one-third. Effluent quality also improved, with BOD consistently below 20 mg/L and TSS under 5 mg/L, demonstrating the technology's superior treatment efficiency and space-saving benefits. It is important to assess the characteristics of sewage to guide the selection of the appropriate treatment technology. A detailed understanding of wastewater properties is crucial for the effective design and operation of collection, treatment, and disposal systems, as well as for managing environmental quality [33,34]. To aid this understanding, typical wastewater characteristics that are commonly measured and quantified include temperature, pH, color, odor, solids, nitrogen, phosphorus, chloride, toxic metals and compounds, Biochemical Oxygen Demand (BOD), and Chemical Oxygen Demand (COD). The characteristics of the sewage are outlined in **Table 1**.

Table 1. Characteristics of sewage.

Parameter	Unit	Value
Inlet Flow Rate to STP	m^3/day	25
pH	-	6.5–8.0
BOD	mg/L	300–400
COD	mg/L	600–700
Total Suspended Solids	mg/L	150
Oil and Grease	mg/L	< 20
Inlet Temperature	^oC	20–35 (ambient)
Total Alkalinity	mg/L	40
Ammonical Nitrogen	mg/L	20
Total Kjheldal Nitrogen	mg/L	45
Total Nitrogen	mg/L	45

Note:
1) All oil in the sewage is of the free-floating variety.
2) The sewage must be devoid of any type of effluent.
3) It is assumed that all COD (Chemical Oxygen Demand) and BOD (Biochemical Oxygen Demand) in the sewage are biodegradable, and the particulate COD will be eliminated through filtration.

In MBR-based STP for the township, Sludge Retention Time (SRT) is controlled by regulating sludge wastage, maintaining MLSS at 8000–12,000 mg/L, and optimizing aeration to enhance biodegradation and minimize sludge production. Hydraulic Retention Time (HRT), typically 4–8 h, is monitored via flow meters and adjusted through automated influent regulation to ensure steady treatment. SRT impacts nutrient removal and sludge stability, while HRT influences organic degradation and system efficiency. Optimized SRT and HRT improve treatment performance, reduce energy consumption, and enhance membrane longevity, ensuring cost-effective, stable, and high-quality effluent production in STPs [35]. In a 65 KLD Membrane Bioreactor (MBR) system, the dewatering process significantly reduces sludge volume, enhancing handling and disposal efficiency. The sludge solid content post-dewatering ranges from 18% to 25%, depending on the dewatering technology used, such as a decanter centrifuge or filter press. MBR-generated sludge has lower water content due to extended Sludge Retention Time (SRT), minimizing sludge disposal frequency. Higher solid content reduces transportation and disposal costs, while improved dewatering efficiency ensures compliance with environmental regulations.

The characteristics of the treated effluent from the STP will comply with the standards set by the Andhra Pradesh Pollution Control Board [36]. A comprehensive understanding of the wastewater composition is crucial for the effective design and operation of the collection, treatment, and disposal systems, as well as for managing environmental quality. The characteristics of the treated water are presented in **Table 2**.

Table 2. Characteristics of treated water.

Parameter	Unit	Value
pH	-	5.5–9.0
BOD	mg/L	20
COD	mg/L	50
Total Suspended Solids	mg/L	< 5
Oil and Grease	mg/L	< 5
Temperature	ºC	20–35 (ambient)
Total Residual Chlorine	mg/L	0.5
Total Nitrogen	mg/L	10

MBR systems offer high-quality effluent by effectively filtering out biomatter, solids, and microorganisms, making the treated water suitable for direct reuse, recycling, or safe environmental discharge. Their design allows independent control of Sludge Retention Time (SRT) and Hydraulic Retention Time (HRT), as sludge solids are retained within the bioreactor. With a compact footprint requiring 50% less space than traditional activated sludge systems due to the absence of clarifiers, MBR systems ensure stable performance by maintaining a higher concentration of Mixed Liquor Suspended Solids (MLSS), enhancing the removal of biodegradable materials. Additionally, they produce less sludge, reducing disposal frequency, while the sludge generated has a higher solid content, improving dewatering efficiency. Overall, MBR systems deliver high treatment efficiency while consistently producing superior-quality effluent.

MBR-based Sewage Treatment Plants (STPs) feature a compact and modular design with an integrated biological treatment system that ensures consistent water quality by eliminating bacteria through membranes, making the treated water suitable for non-potable applications such as gardening, car washing, cooling towers, and construction activities. Operating at higher Mixed Liquor Suspended Solids (MLSS) concentrations (8000–10,000 mg/L) in the aeration tank with extended sludge retention time, these systems generate minimal sludge, which is fully digested, reducing the need for extensive sludge handling infrastructure. MBR technology enables high-flux operation, decreasing the required membrane surface area and reducing the overall footprint of the plant [37]. Energy efficiency is enhanced by eliminating the need for a filtration system, while advanced low-fouling, back-washable membranes minimize chemical cleaning requirements and extend membrane lifespan. Additionally, MBR-based STPs offer lower operational costs, require minimal civil construction with the flexibility of prefabricated membrane modules, and can be quickly upgraded. Their fully automated operation ensures ease of use with minimal maintenance, and the advanced treatment process eliminates the need for tertiary treatment methods like chlorination, sand filtration, or activated carbon filtration. An ergonomic layout further enhances accessibility to all monitoring components, improving operational convenience.

The treatment process for a 65 KLD modular Sewage Treatment Plant (STP) is designed to ensure efficient wastewater treatment within a total footprint of approximately 30 m by 25 m for a flow rate of 65 m^3/day. The process begins with a screen chamber that captures large debris such as rags and plastics, followed by an oil and grease tank for the removal of oils and fats. The sewage is then collected and balanced in the equalization tank, which is preferably underground to facilitate gravity-driven flow through HDPE corrugated pipes. Blowers supply air to the aeration and MBR tanks, where biological treatment occurs in the aeration tank. The MBR tank houses MBR modules that utilize microfiltration (MF) and ultrafiltration (UF) membranes for effective filtration. These modules are supported by an MBR skid for efficient stacking. Further treatment includes a dosing system for pH correction, chlorine dosing, and UV disinfection before the treated effluent is collected in the treated water tank. Finally, sludge dewatering is performed using a decanter centrifuge, ensuring effective sludge management. MBR systems offer significant space savings compared to conventional Activated Sludge Process (ASP) STPs due to the elimination of secondary clarifiers and higher MLSS concentrations, allowing for smaller aeration tanks. Space requirements for different capacities are defined in **Table 3**.

Table 3. Space requirements for different capacities.

STP Capacity	Traditional ASP Footprint (m^2)	MBR System Footprint (m^2)	Space Savings (%)
50 KLD	~450–500	~250–300	40%–50%
65 KLD	~585	~325–350	40%–45%
100 KLD	~900	~500	40%–45%
500 KLD	~4500	~2500	40%–45%

The MBR system enhances efficiency by eliminating the need for secondary clarifiers, significantly reducing the overall land area required for installation. The prefabricated modular design ensures flexible installation, making it well-suited for constrained locations. These advantages make MBR technology an ideal choice for sewage treatment in townships, urban areas, and space-limited sites, offering a compact, high-performance, and adaptable solution for wastewater management.

Membrane Bioreactor (MBR) systems are recognized for their energy efficiency in wastewater treatment. Studies show that membrane-related modules consume approximately 0.5–0.7 kWh per cubic meter (kWh/m^3) of treated water, with flat sheet membranes exhibiting 33%–37% higher energy consumption than hollow fiber configurations [38]. A case study from the Kaarst-Nordkanal MBR Plant demonstrated a 20% reduction in aeration energy consumption through process optimizations. While direct data for a 65 KLD MBR system is limited, similar systems achieve comparable efficiency, influenced by membrane type, system design, and operational strategies. Optimizing processes further enhances energy savings, making MBR a viable solution for township wastewater treatment [39].

4. Conclusion

The graphical representation of sewage water and treated water characteristics was carried out using Python programming. The parameter values for sewage water and treated water were plotted side by side for visual comparison as shown in **Figure 7**. The graphical representation obtained from Python programming highlights the comparative analysis between sewage water and treated water based on selected parameters. The results show a significant reduction in pollutant concentrations after treatment. The graphical results emphasize the overall effectiveness of the treatment process in improving water quality by reducing pollutant concentrations across all selected parameters. This study emphasizes the importance of advanced data visualization techniques in evaluating and communicating the efficiency of wastewater treatment processes.

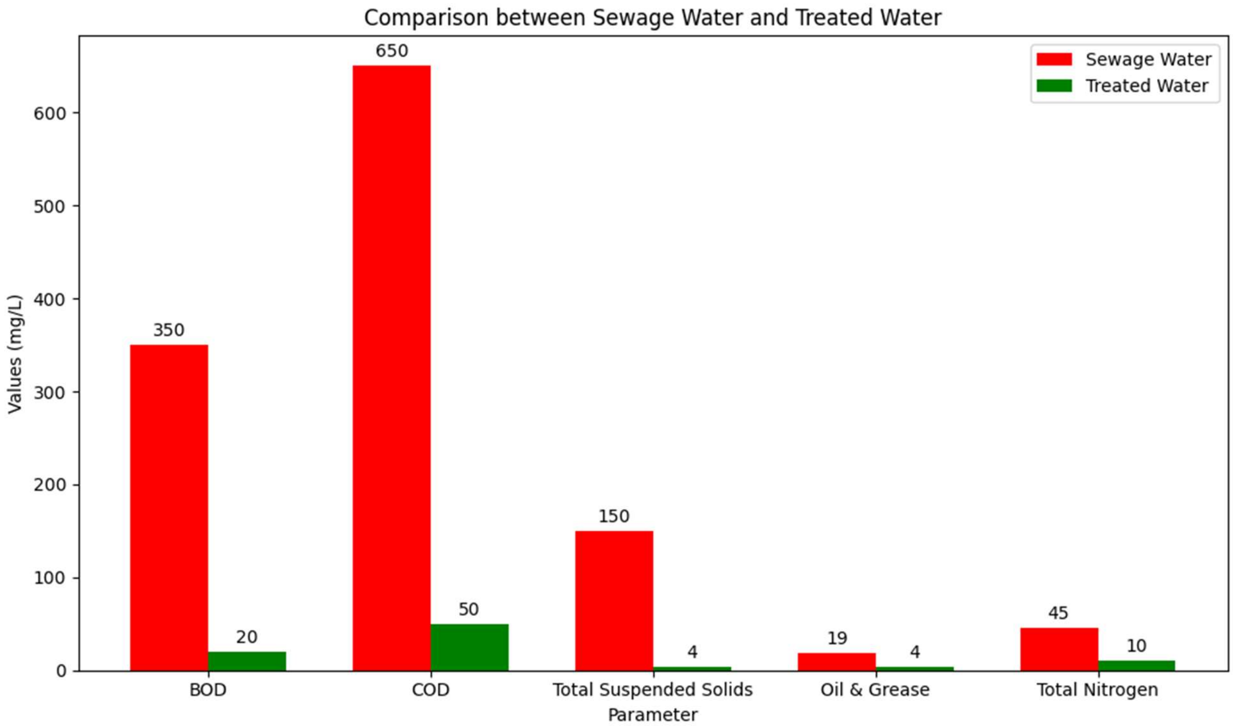

Figure 7. Comparison between sewage water and treated water using the Python computer programming language.

The proposed Sewage Treatment Plant (STP) project will adhere to a comprehensive quality control plan, ensuring the proper installation, testing, and commissioning of the system. This program guarantees the reliability and accuracy of the sewage treatment process, ensuring that the treated water meets the standards set by the Andhra Pradesh Pollution Control Board (APPCB). The quality control procedures will involve monitoring key data such as calibration dates, operating conditions, and characteristics of both sewage inlet and outlet. The quality control program will be implemented at various stages:

1) During initial installation,
2) After erection and commissioning,
3) During routine operation,
4) Following extended periods of inactivity,
5) Upon detection of any malfunctions in system components.

Regular checks will be conducted on the operating components of the STP, with a defined maintenance period (e.g., weekly) to ensure alignment with technical specifications throughout both the installation and operational phases. The frequency of maintenance will be determined based on factors like system stability under prevailing conditions (e.g., sewage flow, temperature, pressure), sewage quality, and the potential risk of operational failures that could go unnoticed during normal operations. Calibrations of the associated instruments will be performed regularly, and over time, as sufficient operational data is collected, the frequency of monitoring will be adjusted to balance the various factors mentioned above. To optimize the monitoring process, it is recommended that equipment manufacturer data sheets and operational charts be used to track the performance of each component. In the event of significant operational deviations, corrective actions will be promptly undertaken. The project will be implemented in two phases: the first will focus on the STP and its civil infrastructure, including an equalization tank, while the second will involve the laying of the sewage network, including manholes and HDPE sewage lines. The total investment required for the STP is estimated at Rs. 174.57 lakh, with an additional Rs. 198.68 lakh for the sewerage network. Post-commissioning, the operation and maintenance of the 65 KLD MBR-based STP will be carried out with an investment of approximately Rs. 42.48 lakh.

The 65 KLD Membrane Bioreactor (MBR) system features a fully automated operation with advanced real-time monitoring for efficient performance management. Integrated Supervisory Control and Data Acquisition (SCADA) systems enable remote monitoring, automated membrane cleaning, and predictive fault detection, reducing manual intervention. Automated backwash and aeration control optimize membrane performance, minimizing fouling and extending membrane lifespan. The system provides alerts for maintenance needs, ensuring timely interventions and preventing failures. This high level of automation enhances operational ease, reduces labor costs, and ensures consistent treatment efficiency, making it ideal for township Sewage Treatment Plants (STPs) with minimal operator supervision.

Author contributions: Conceptualization, VKS and BNKR; methodology, VKS and TSK; software, VKS and TSK; validation, BNKR and TSK; formal analysis, VKS and BNKR; investigation, BNKR and TSK; resources; data curation, VKS; writing—original draft preparation, VKS; writing—review and editing, BNKR and TSK; visualization, VKS; supervision, BNKR and TSK; project administration, BNKR and TSK. All authors have read and agreed to the published version of the manuscript.

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Abbreviations

A.P.	Andhra Pradesh
APPCB	Andhra Pradesh Pollution Control Board
ASP	Activated Sludge Process
BOD	Biochemical Oxygen Demand
CAS	Combined Activated Sludge
COD	Chemical Oxygen Demand
CPHEEO	Central Public Health Environmental and Engineering Organization
DEWATS	Decentralized Water Treatment System
eARGs	Extracellular Antimicrobial Resistance Genes
HDPE	High Density Polyethylene
HRT	Hydraulic Retention Time
KLD	Kilo Liters per day
MBBR	Moving Bed Bio Reactor
MBR	Membrane Bio Reactor
MF	Microfiltration
MLSS	Mixed Liquor Suspended Solids
MoEF&CC	Ministry of Environment, Forest and Climate Change
NBC	National Building Code
PAC	Powdered Activated Carbon
PLC	Programmable Logic Controller
SBR	Sequential Batch Reactor
SRT	Sludge Retention Time
STP	Sewage Treatment Plant
TMP	Trans Membrane Pressure
TSS	Total Suspended Solids
UASB	Upflow Anaerobic Sludge Blanket Reactor
UF	Ultra Filtration
UV	Ultra Violet
WHO	World Health Organization
ZLD	Zero Liquid Discharge

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