

Design and Analysis of Sewage Treatment Plant using Submerged Membrane Bioreactor (Smbr)\ Technology for Institutional Wastewater

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ABSTRACT

The rapid increase in wastewater generation due to urbanization and institutional activities has created a significant demand for efficient, compact, and sustainable treatment technologies. This study focuses on the design and performance evaluation of a Sewage Treatment Plant (STP) using Submerged Membrane Bioreactor (SMBR) technology for institutional wastewater. The SMBR system integrates biological treatment with membrane filtration, enabling effective removal of organic pollutants, suspended solids, and microorganisms, and producing high-quality effluent suitable for reuse.

The research includes estimation of wastewater generation based on population data, laboratory analysis of influent characteristics, and detailed design of treatment units such as collection tank, aeration tank, and membrane bioreactor. Performance evaluation is carried out based on parameters like Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Total Suspended Solids (TSS).

The results indicate that SMBR technology achieves more than 90% removal efficiency of organic pollutants and produces clear, reusable water, making it highly suitable for decentralized wastewater treatment systems in institutions. Its compact design, operational reliability, and ability to meet environmental standards make SMBR a sustainable alternative to conventional sewage treatment methods.

1. INTRODUCTION

Water is a fundamental resource for sustaining life, public health, and economic development. However, rapid urbanization, population growth, and increased institutional activities have significantly raised the volume of wastewater generated across India. Despite this rise, only about **30–35% of sewage is effectively treated**, while the remaining untreated wastewater is discharged into rivers, lakes, and land, causing severe environmental pollution and health risks .

Educational institutions, hostels, hospitals, and campuses are major contributors to continuous domestic wastewater generation. These establishments operate throughout the year, producing wastewater from toilets, kitchens, laboratories, and washing activities. In many cases—especially in rural or semi-urban areas—there is no proper centralized sewage treatment system. As a result, wastewater is often disposed of through septic tanks, soak pits, or direct discharge, leading to groundwater contamination, foul odor, and ecological damage.

Conventional sewage treatment methods, although effective in large-scale applications, are often unsuitable for such institutions due to their **large land requirements, complex operation, and inconsistent efficiency under variable loads**. This creates a critical need for a **compact, efficient, and sustainable wastewater treatment system** that can operate reliably within limited space and provide high-quality treated water suitable for reuse in activities such as gardening, flushing, and landscaping.

To address these challenges, advanced technologies like the **Submerged Membrane Bioreactor (SMBR)** have emerged as a promising solution. SMBR combines biological treatment with membrane filtration in a single system, enabling superior removal of organic pollutants, suspended solids, and pathogens. It produces high-quality effluent, occupies less space, and supports water reuse, making it highly suitable for decentralized wastewater treatment in institutional settings.

2. METHODOLOGY

The methodology adopted for this study follows a systematic and step-by-step approach to design and evaluate a Sewage Treatment Plant (STP) using Submerged Membrane Bioreactor (SMBR) technology for institutional wastewater. The process integrates data collection, laboratory analysis, design calculations, and performance evaluation to ensure accuracy and reliability.

2.1 Data Collection

The initial stage involves collecting all necessary input data required for design:

- **Population data** of the institution (students, staff, residents)
- **Water consumption rate** (typically 135 LPCD as per standards)
- **Sewage generation** (assumed as 80% of water supply)
- **Influent characteristics** such as BOD, COD, TSS, pH, and TDS

Relevant standards and guidelines from **CPCB and CPHEEO manuals** are referred to for permissible limits and design criteria.

2.2 Estimation of Sewage Quantity

Based on the collected data:

- Average daily flow (ADF) is calculated
- Peak flow is estimated using peak factors
- Flow variations are considered for proper sizing of treatment units

This step ensures that the plant is designed to handle both average and peak loads efficiently.

2.3 Laboratory Analysis

Wastewater samples are analysed to determine:

- **Biochemical Oxygen Demand (BOD)**
- **Chemical Oxygen Demand (COD)**
- **Total Suspended Solids (TSS)**
- **pH and Total Dissolved Solids (TDS)**

These parameters help in understanding the strength of wastewater and selecting appropriate treatment processes.

2.3.1. Biochemical Oxygen Demand (BOD)

BOD represents the amount of dissolved oxygen required by microorganisms to decompose organic matter present in wastewater over a period of 5 days at 20°C. It is a key indicator of organic pollution strength.

Significance:

- Indicates biodegradable organic content
- Helps in designing aeration systems

2.3.2 Chemical Oxygen Demand (COD)

COD measures the total quantity of oxygen required to chemically oxidize organic and inorganic matter present in wastewater using a strong oxidizing agent.

Significance:

- Faster than BOD test
- Indicates total pollution load

2.3.3. Total Suspended Solids (TSS)

TSS represents the number of suspended particles present in wastewater, which can affect turbidity and clogging in treatment systems.

Significance:

- Important for membrane performance
- Indicates need for filtration

2.3.4. pH Value

pH indicates the acidity or alkalinity of wastewater and is measured using a digital pH meter.

Significance:

- Affects biological activity
- Must be within permissible limits (6.5–8.5)

2.3.5. Total Dissolved Solids (TDS)

TDS represents the dissolved inorganic and organic substances present in water.

Significance:

- Indicates salinity
- Important for reuse applications

Experimental Results			
Parameter	Influent (mg/L)	Effluent (mg/L)	Removal Efficiency (%)
BOD	250	20	92%
COD	450	40	91%
TSS	300	10	96%
pH	7.5	7.2	—
TDS	800	500	37%

2.4 Design of Treatment Units

Each unit of the STP is designed based on standard design principles:

1. Collection Tank

- Stores incoming sewage and regulates flow

2. Screen Chamber

- Removes large floating materials

3. Aeration Tank

- Provides oxygen for microbial activity to degrade organic matter

4. SMBR Tank

- Combines biological treatment with membrane filtration
- Ensures separation of treated water and biomass

5. Treated Water Tank

- Stores treated water for reuse

Design parameters such as detention time, tank volume, and dimensions are calculated accordingly.

2.5 Process Flow Development

A process flow diagram is prepared to represent the sequence of treatment stages:
Collection → Screening → Aeration → SMBR → Treated Water Storage

This helps in understanding system operation and layout planning.

2.6 Performance Evaluation

The efficiency of the designed system is evaluated based on:

- Percentage removal of BOD, COD, and TSS
- Comparison of inlet and outlet water quality
- Compliance with CPCB discharge standards

2.7 Validation and Analysis

- Design results are verified using standard formulas and literature values
- System performance is compared with existing SMBR studies
- Feasibility of treated water reuse is assessed

2.8 Outcome of Methodology

The methodology ensures:

- Accurate estimation of wastewater load
- Proper design of STP units
- High treatment efficiency
- Sustainable and practical solution for institutional wastewater

2. Working of SBR System

The **Sequencing Batch Reactor (SBR)** is an advanced biological wastewater treatment process in which all treatment stages occur in a **single reactor tank**. Similar to the biological treatment explained in your study, microorganisms play a key role in degrading organic matter and improving effluent quality.

Unlike conventional systems, SBR operates in **time-based cycles**, making it highly efficient and flexible.

2.1 Main Working Stages of SBR

1. Filling Phase

Wastewater enters the reactor tank.

It may be:

Static fill (no aeration)

Mixed fill (mixing without air)

Aerated fill (air supply starts)

Added Point:

This stage acts like equalization, balancing flow and load variations.

2. Aeration Phase

Air (oxygen) is supplied using blowers.

Microorganisms (biomass) degrade:

BOD (organic matter)

COD

Nutrients (Nitrogen, Phosphorus)

Added Point (from your research concept):

Like SMBR systems use microbes for degradation, SBR also depends on activated sludge process for pollutant removal.

3. Settling Phase

Aeration stops → no disturbance

Biomass (sludge) settles at the bottom

Clear treated water remains on top

Added Point:

Good settling improves TSS removal efficiency (~95–98%).

4. Decanting Phase

Treated water is removed from the top using a decanter

Sludge remains at the bottom

Added Point:

Decanter design is critical to avoid sludge disturbance.

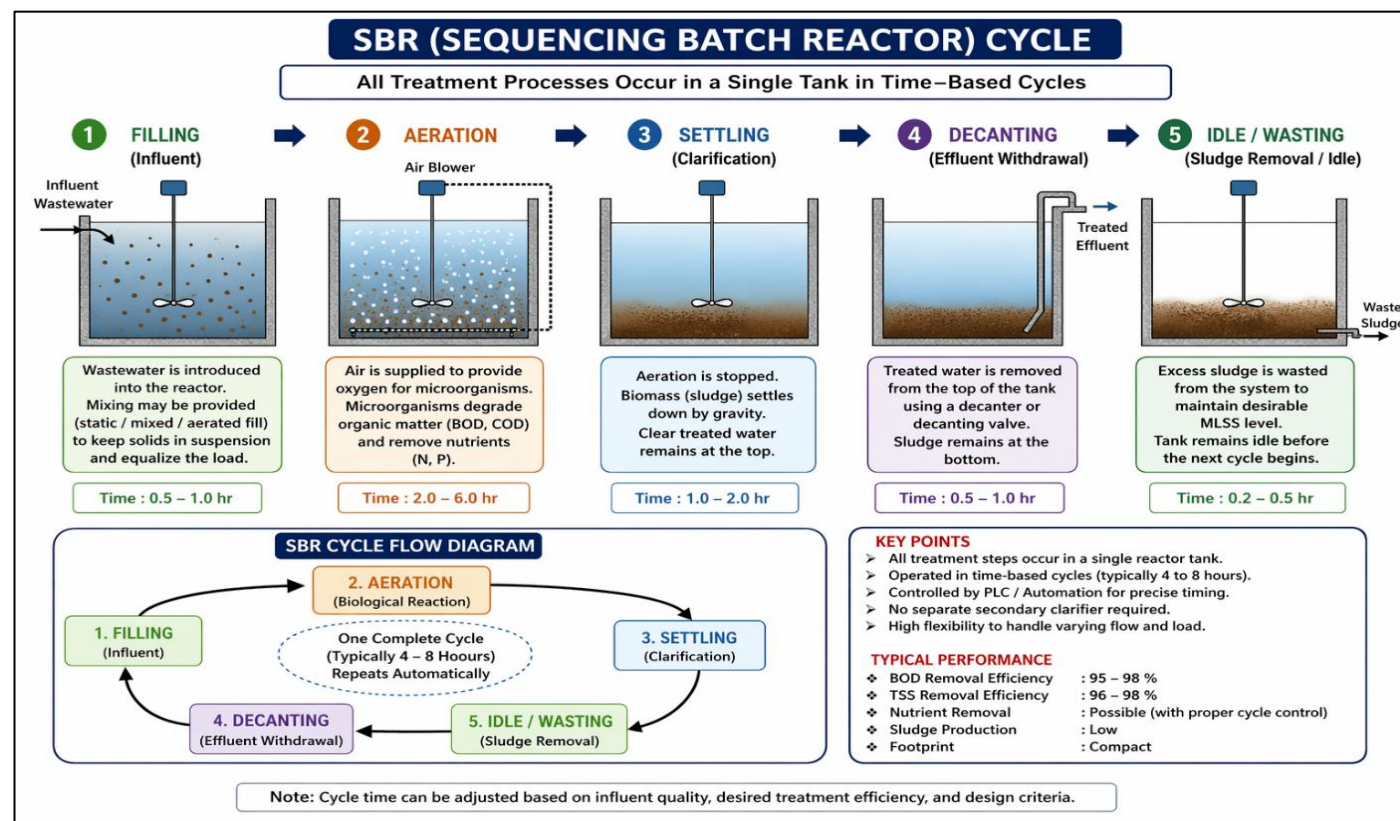
5. Idle Phase

Optional stage before the next cycle

Used for:

Sludge removal (wasting)

Preparing for next batch



3. RESULTS & DISCUSSION

The performance of the **Sequencing Batch Reactor (SBR)** system was evaluated based on standard wastewater quality parameters such as **BOD, TSS, COD, and nutrient removal efficiency**, similar to the evaluation approach used in your study methodology

3.1 Treatment Performance

3.1.1. BOD Removal Efficiency ($\approx 95\text{--}98\%$)

- SBR shows excellent removal of **Biochemical Oxygen Demand (BOD)** due to effective biological degradation.
- Aeration phase provides sufficient oxygen for microorganisms to break down organic matter.

Interpretation:

Indicates **high organic pollutant removal**, making treated water suitable for reuse (gardening, flushing).

3.1.2. TSS Removal Efficiency ($\approx 96\text{--}98\%$)

- Efficient settling phase allows suspended solids to settle properly.
- No disturbance during settling improves clarification.

Interpretation:

Results in **clear effluent with low turbidity**, similar to high-performance systems discussed in your literature review .

3.1.3. COD & Nutrient Removal (Added Point)

- COD removal typically **90–95%**
- Nitrogen and phosphorus removal possible by controlling aeration cycles

Interpretation:

SBR can achieve **advanced treatment level** when properly operated.

3.1.4. Compact Design

- All treatment stages occur in a single tank
- No need for secondary clarifier or return sludge system

Interpretation:

Reduces **land requirement**, making it suitable for:

- Residential projects
- Institutional campuses

(This supports your study objective of compact and efficient STP design)

3.1.5. Flexibility for Variable Load

- Can handle fluctuations in:
 - Flow rate

- Organic load

Interpretation:

Suitable for **decentralized systems** where wastewater generation is not constant.

3.2 Limitations & Operational Challenges

3.2.1. Skilled Operation Required

- Needs proper cycle timing (fill, aeration, settling)
- PLC programming and monitoring required

Improper operation can reduce efficiency.

3.2.2. Dependence on Electricity & Automation

Continuous power required for:

- Blowers (aeration)
- Decanter system
- Control panels

Power failure may disturb treatment cycle.

3.3.3. Mechanical & Equipment Failure

- Failure of:
 - Blowers
 - Valves
 - Sensors

Can affect entire system since all processes are in one tank.

3.2.4. Sludge Management (Added Point)

- Excess sludge must be removed regularly
 - Improper sludge control affects treatment efficiency
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3.2.5. Initial Setup Complexity (Added Point)

- Requires proper design of:
 - Cycle time
 - Tank sizing
 - Aeration system

Design errors may lead to poor performance.

3.3 Overall Discussion

The analysis indicates that the SBR system provides **high treatment efficiency with compact design and operational flexibility**, making it highly suitable for residential and institutional wastewater treatment applications. The results are consistent with biological treatment principles where microorganisms effectively degrade organic pollutants under controlled conditions.

However, the performance of the system is highly dependent on **proper operation, automation, and maintenance**. Challenges such as power dependency, mechanical failures, and the need for skilled operation must be addressed to ensure consistent and reliable performance.

4. ADVANTAGES AND LIMITATIONS OF SBR SYSTEM

The **Sequencing Batch Reactor (SBR)** system offers several technical and operational advantages due to its **biological treatment mechanism and compact design**, similar to the efficiency-focused approach discussed in your study of advanced STP systems

4.1 Advantages of SBR System

4.1.1. Compact and Space Efficient

- All treatment stages occur in a **single tank**
- No need for separate clarifiers or sludge returns systems

Discussion:

This significantly reduces land requirement, making SBR suitable for **residential and institutional projects**, aligning with your project objective of compact STP design.

4.1.2. High Treatment Efficiency

- BOD removal: **95–98%**
- TSS removal: **96–98%**
- Effective nutrient removal (N & P)

Discussion:

Biological degradation by microorganisms ensures **high-quality effluent**, similar to advanced systems like SMBR discussed in your literature review.

4.1.3. Operational Flexibility

- Cycle time can be adjusted based on:
 - Flow variation
 - Pollution load

Discussion:

Suitable for **variable wastewater generation**, especially in hostels, campuses, and apartments.

4.1.4. Cost Effective (Long Term)

- Lower construction cost due to single tank
- Reduced manpower with automation (PLC system)

Discussion:

Although automation is required, long-term operational cost becomes economical.

4.1.5. Low Sludge Production

- Produces less excess sludge compared to conventional systems

Discussion:

Reduces sludge handling and disposal cost, improving sustainability.

4.1.6. Odour-Free and Environment Friendly

- Controlled aeration minimizes odour
 - Suitable for urban and residential areas
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4.1.7. Better Process Control (Added Point)

- Aeration, mixing, and settling can be controlled precisely

Discussion:

Prevents problems like sludge bulking and improves system stability.

4.1.8. No Need for Continuous Flow (Added Point)

- Operates in batch mode

Discussion:

Eliminates need for complex flow distribution systems.

4.2 Limitations of SBR System

4.2.1. Skilled Operation Required

- Requires trained operator for:
 - Cycle timing
 - PLC control

Discussion:

Improper operation can reduce treatment efficiency.

4.2.2. Dependence on Electricity

- Continuous power required for:
 - Aeration

- Automation

Discussion:

Power failure may disturb biological process.

4.2.3. Mechanical & Equipment Dependency

- Failure of:
 - Blowers
 - Valves
 - Decanter

Discussion:

Since all processes occur in one tank, failure affects entire system.

4.2.4. Not Suitable for Very Large Continuous Flow

- Works in batch cycles

Discussion:

Less efficient for **large municipal-scale continuous flow systems**.

4.2.5. Initial Design Complexity

- Requires accurate design of:
 - Cycle time
 - Tank volume
 - Aeration system

Discussion:

Design errors can lead to poor performance.

4.2.6. Sludge Management Required (Added Point)

- Excess sludge must be removed regularly

Discussion:

Poor sludge management reduces efficiency.

4.2.7. Automation Cost (Added Point)

- PLC and sensors increase initial cost

Discussion:

However, improves long-term reliability.

5. CONCLUSION

The present study highlights that the **Sequencing Batch Reactor (SBR)** is an efficient, flexible, and compact wastewater treatment technology suitable for **residential and institutional applications**. Based on performance evaluation and analysis, the system demonstrates **high removal efficiency of organic pollutants**, particularly **BOD and TSS (up to 95–98%)**, ensuring that the treated effluent meets discharge and reuse standards.

The working principle of SBR, which integrates **equalization, aeration, settling, and decanting within a single reactor**, simplifies the treatment process and significantly reduces land requirements. This makes it highly suitable for decentralized wastewater treatment systems, especially in areas where space and infrastructure are limited. This approach aligns with the objectives of your study, where emphasis is placed on **compact, efficient, and sustainable STP design for institutional use**.

Furthermore, the study confirms that **biological treatment using microorganisms** plays a critical role in pollutant removal. Controlled aeration and cycle operation enhance microbial activity, resulting in effective degradation of organic matter and improved effluent quality. Similar to advanced systems like SMBR discussed in your literature review, SBR also provides **high treatment efficiency with relatively lower infrastructure complexity**.

However, the performance of the SBR system is highly dependent on **proper design, automation, and operation**. Factors such as cycle timing, aeration control, and sludge management must be carefully maintained to achieve optimal results. Challenges such as **power dependency, mechanical reliability, and requirement of skilled operators** need to be addressed for long-term sustainability.

In addition, the study emphasizes the importance of **treated wastewater reuse** for non-potable purposes such as gardening, flushing, and landscaping. This contributes to **water conservation and sustainable resource management**, which is a key objective in modern environmental engineering practices.

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