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Design of Pre Treatment Units by Integrating Moving Bed Biofilm Reactor for Improving Efficiency of Sewage Treatment Plant

G. Venu Ratna Kumari[1], D. Satyanarayana[2], R.V. Ramana[3], K. Maria Das[4], M. Satish Kumar[5], M.V. Raju[6]

[1]Senior Assistant Professor, Department of Civil Engineering, Vikas College of Engineering and Technology, Vijayawada Rural, Andhra Pradesh, India.

[2]Professor, Department of Mechanical Engineering, Vignan's Foundation for Science, Technology and Research, Deemed to be University, Guntur, Andhra Pradesh, India.

[3]Assistant Professor, Department of CEPC, Vignan's Foundation for Science, Technology and Research, Deemed to be University, Guntur, Andhra Pradesh, India.

[4]Assistant Professor, Department of Chemistry, School of ASH, Vignan's Foundation for Science, Technology and Research, Deemed to be University, Guntur, Andhra Pradesh, India.

[5]Professor and HOD, Department of Civil Engineering, Kallam Haranadha Reddy Institute of Technology, Chowdavaram, Guntur, Andhra Pradesh, India.

[6]Assistant Professor, Department of CEPC, Vignan's Foundation for Science, Technology and Research, Deemed to be University, Guntur, Andhra Pradesh, India.

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KEYWORDS

Public Health, Sewage Treatment Plant (STP), Pretreatment Units, Moving Bed Biofilm Reactor (MBBR) and Environment

ABSTRACT:

With the rapid pace of urbanization and population growth, the generation of domestic wastewater has increased significantly, placing immense pressure on existing sewage treatment infrastructure. Untreated or inadequately treated sewage discharged into natural water bodies poses serious environmental and public health risks due to the presence of organic matter, suspended solids, nutrients, oils, and other contaminants. Therefore, the need for efficient and sustainable treatment technologies has become more critical than ever.

The effectiveness of any sewage treatment plant (STP) greatly depends on the design of its pre-treatment units, which are responsible for removing large solids, grit, oils, and greases before biological treatment begins. Properly designed pre-treatment units enhance the overall efficiency of the plant, reduce operational issues, and protect downstream equipment and biological processes. Among various modern treatment technologies, the Moving Bed Biofilm Reactor (MBBR) stands out as a compact and efficient system for biological wastewater treatment. By integrating the advantages of both activated sludge and fixed-film systems, MBBR offers higher treatment efficiency in a smaller footprint. It is especially effective in removing organic matter, nitrogen compounds, and other pollutants from domestic wastewater. This study focuses on the design of pre-treatment units integrated with MBBR technology, based on detailed wastewater analysis. The objective is to improve the operational efficiency and reliability of the sewage treatment plant while ensuring compliance with environmental discharge standards

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1. Introduction

Pollution, driven by rapid population growth and industrialization, poses a significant threat to our environment and quality of life. Water, a vital resource, is particularly vulnerable to degradation. Water pollution, characterized by changes in physical, chemical, and biological properties, hinders its various beneficial uses. Sewage and industrial effluents are major contributors to water pollution, comprising human waste, domestic, and industrial contaminants. To address this challenge, Sewage Treatment Plants (STPs) play a crucial role. These facilities are designed to receive, treat, and discharge wastewater safely into water receiving systems. STPs employ physical, chemical, and biological processes to remove contaminants. Advances in technology, such as Moving Bed Biofilm Reactor (MBBR), have enhanced the efficiency of wastewater treatment. MBBR uses biofilm carriers in an aerated tank to promote the growth of microorganisms that break down pollutants. Geographic Information System (GIS) technology has been integrated into wastewater treatment processes for efficient mapping and management. GIS enables the visualization and analysis of spatial data, aiding in the planning and design of STPs. This study focuses on characterizing domestic wastewater to design and layout four 30 MLD STPs. Parameters such as pH, Nitrates, Chlorides and Biochemical Oxygen Demand (BOD) are measured to determine the treatment requirements. The integration of MBBR technology enhances the effectiveness and sustainability of wastewater treatment processes contributing to environmental conservation and public health.

The scope of the project encompasses a comprehensive study and design of Sewage Treatment. Plants (STPs) to address the challenges posed by water pollution. The key aspects of the project include as follows:

Characterization of Wastewater: Conducting tests to determine the physical, chemical, and biological properties of domestic and industrial wastewater to understand the pollutants present and their concentrations.

Design of STPs: Designing four 30 MLD STPs based on the wastewater characterization results. This includes determining the treatment processes and units required to effectively remove contaminants and meet regulatory standards.

Integration of MBBR Technology: Incorporating Moving Bed Biofilm Reactor (MBBR) technology into the design for enhanced treatment efficiency. MBBR utilizes biofilm carriers to facilitate the growth of microorganisms that break down pollutants.

Layout Design: Developing a preliminary layout for the four STPs based on the treatment requirements and available space. The layout design includes the arrangement of treatment units and infrastructure.

Environmental Impact Assessment: Assessing the environmental impact of the proposed STPs and ensuring compliance with regulatory standards to minimize adverse effects on the environment.

Sustainability and Reuse: Exploring options for the sustainable treatment of wastewater and the reuse of treated effluent for non-potable purposes, such as irrigation or industrial use.

2. Objectives:

✓ Characterize domestic wastewater to understand pollutant levels. And Design Pre Treatment Units by Integrating Moving Bed Biofilm Reactor for Improving Efficiency of sewage treatment plant based on wastewater analysis.

3. Study Area:

Tenali has been selected for the present study, situated in the Guntur District of Andhra Pradesh State, India. The study area is located with coordinates of 16.239°N 80.645°S, covering an area of 29.56 km^2. Paddy is the major crop in the study area, and Tenali is one of the principal trade centers of paddy in the state of Andhra Pradesh.

4. Characteristics of Wastewater:

As the results of raw sewage i.e. TS (TSS & TDS), Oil & Grease, BOD are exceeding from their permissible values. Hence, further treatment of raw sewage is required before its disposal into surface streams. Characteristics of wastewater and Permissible Limits of wastewater has been shown in the Table 1 and Table2.

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Table 1. Characteristics of Wastewater

Sample Details	pH (Scale)	Total Solids (mg/l)	TSS (mg/l)	TDS (mg/l)	Chlorides (mg/l)	Nitrates (mg/l)	Oil & Grease	BOD (mg/l)
A1	7.1	934	272	662	114	60	24.8	144
A2	7.3	470	132	338	96	20	8.4	236
A3	6.9	2096	1270	826	93	45	46.8	186
A4	7.3	569	38	531	89	20	7.6	200
A5	7.5	470	132	338	96	20	8.4	236
A6	6.8	565	38	531	89	20	7.6	200
A7	7.1	2100	1125	820	90	42	26.8	210
A8	7.3	470	132	338	96	20	8.4	236
A9	6.8	1895	950	810	89	44	34.2	190
Avg. Results	7.3	1064	454	577	94	32	19	204

Table 2. Permissible Limits of Wastewater Characteristics (as per the Environment (Protection) Rules (1986)).

S. No	Parameter	Permissible Limits
1	pH	5.5-9.0
2	Color & Odour	NA
3	TDS	100 mg/l
4	TSS	100 mg/l
5	TDS	N/A
6	Nitrates	50 mg/l
7	Chloride	600 mg/l
8	Oil & Grease	10 mg/l
9	BOD	30 mg/l
10	COD	250 mg/l

4. Analysis and Design Calculations:

Pre-treatment unit operations are critical in removing large particles, grit, oils, and other impurities that may interfere with downstream biological processes. These units often contain screening, grit removal, and skimming tanks, which are all constructed depending on the hydraulic and physical properties of the incoming sewage. Proper design and size of these components is critical to ensuring the smooth functioning of the

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MBBR system, lowering maintenance issues and raising overall plant efficiency.

4.1. Design Calculation for Bar Screen:

Maximum Flow: 30 MLD = 0.347 m^3/s

Bar Type: Mild Steel (M.S) Bars

Bar Dimensions: 10 mm × 50 mm

(10 mm side facing the flow)

Clear Spacing Between Bars: 30 mm

(Note: Typical range for medium screens is 6–40 mm)

Design Flow Velocity: 0.8 m/s

(Recommended range: 0.6–0.9 m/s)

Screen Opening Area Calculations

- Net Submerged Area of Screen Openings = Flow / Velocity = 0.347 / 0.8 = 0.44 m^2
- Gross Vertical Area of Screen

(at 60° inclination) = 0.44 × sin(60°) = 0.38 m^2

Channel and Bar Screen Dimensions

- Assumed Depth of Flow: 0.3 m
- Required Channel Width = Gross Vertical Area / Depth = 0.38 / 0.3 = 1.30 m
- Flow Velocity in Screen Chamber = 0.347 / (0.3 × 1.3) = 0.89 m/s *(Exceeds the minimum self-cleansing velocity of 0.42 m/s)*

Bar Spacing and Count

- Total Width per Bar (including spacing) = 30 mm (clear spacing) + 10 mm (bar width) = 40 mm = 0.04 m
- Number of Bars Required = 1.3 / 0.04 = 33 bars
- Actual Width of Screen = 33 × 0.04 = 1.32 m
- Actual Depth of Sewage Flow = Gross Vertical Area / Actual Width = 0.38 / 1.32 ≈ 0.3 m
- Freeboard Provided: 0.5 m
- Total Depth of Screen = 0.3 m (flow depth) + 0.5 m (freeboard) = 0.8 m

Final Screen Dimensions

- Screen Size: 1.32 m (width) × 0.8 m (depth)

4.2. Design of Grit Chamber:

To prevent the scouring of already-settled particles, the flow velocity should not exceed the critical horizontal velocity (Vc).

The velocity relationship is expressed as: L/H=Vc/V0

Where:

- L = Length of the grit chamber
- H = Depth of flow
- Vc = Critical velocity
- V_0 = Actual horizontal velocity

Critical Velocity Calculation

As per Rao and Dutta (2007), the critical velocity (Vc) is given by:

Vc= Squr. (8g/) f·β (Gs−1) d

Where:

- g = Acceleration due to gravity = 9.81 m/s^2
- f = Darcy-Weisbach friction factor = 0.03 (for gritty matter)
- β = Constant

= 0.04 for uniform granular sand

= 0.06 for non-uniform sticky material

- Gs = Specific gravity of particles = 2.65 (for sand)
- d = Diameter of particle = 0.2 mm = 0.0002 m

Substituting the values:

Vc=8×9.81×0.06 × (2.65−1) × 0.0002=0.228 m/s

Typical range: 0.17 – 0.26 m/s

Design Criteria

- Target Particle: Sand particles with a diameter of 0.2 mm and a specific gravity of 2.65
- Critical Velocity (Vc): 0.228 m/s

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- Selected Horizontal Velocity: 0.2 m/s *(< Vc to avoid scouring)*
- Detention Time: 60 seconds *(typically ranges from 40–60 seconds)*

To maintain the desired flow velocity, hydraulic structures like Sutro weirs or Parshall flumes may be provided.

Grit Chamber Dimensions

- Length = Velocity × Detention Time = 0.2 × 60 = 12 m
- Volume = Discharge × Detention Time = 0.347 × 60 = 20.82 m^3
- Cross-Sectional Area of Flow = Vol./ Length = 20.82 / 12 = 1.735 m^2
- Assumed Width of Chamber = 3 m
- Required Depth = Area / Width = 1.735 / 3 = 0.58 m

Grit Storage Calculation

Assumed Grit Generation: 0.05 m^3 per 1000 m^3 of sewage

Even though the grit is continuously raked, it is standard practice to provide 8 hours of grit storage based on average flow conditions.

- Average Sewage Flow: 30,000 m^3/day
- Grit Storage Volume Required:

Storage Volume = $(30,000×8×0.05)/24×1000=0.5$ m

Cross-sectional Area of Flow: 1.735 m^2

Required Storage Depth:

Storage Depth=0.51.735≈0.3 m

Total Depth of Grit Chamber

- Flow Depth: 0.58 m
- Grit Storage Depth: 0.3 m
- Freeboard Provided: 0.5 m

Total Depth=0.58+0.3+0.5=1.38 m≈1.5 m

Final Dimensions of Grit Chamber

- Length: 12 m
- Width: 3 m
- Total Depth: 1.5 m

→ Therefore, the final size of the grit chamber is: 12 m × 3 m × 1.5 m.

4.3. Skimming Tank Design

- Detention Time: 3 to 5 minutes
- Compressed Air Requirement: 300 to 6000 m^3 per million liters of sewage

The required surface area for the skimming tank is calculated using the formula:

$A=(0.00622×q)/V_r$

Where:

- A = Surface area required (m^2)
- q = Flow rate of sewage (m^3/day)
- V_r = Minimum rising velocity of greasy materials = 0.25 m/min (commonly used value)

Tank Dimensions

A square tank layout is proposed with the following dimensions:

- Side Length = 28 m
- Surface Area = 28 × 28 = 784 m^2

A skimming tank measuring 28 m × 28 m provides a surface area of 784 m^2, meeting the design requirements for grease removal based on typical flow rates and material rise velocities.

5. Conclusions of Designed Pre-Treatment Units:

The sewage treatment a way is designed to take into account major wastewater properties such as pH, total solids, nitrites, chlorides, fats, oils, and grease. Moving Bed Biofilm Reactor (MBBR) technology provides a more compact alternative than conventional treatment systems, greatly lowering the footprint required for installation. In fact, compared to the standard activated sludge method, the space required is decreased by nearly 49%. MBBR systems are extremely efficient in removing organic matter, nitrogen, and other impurities from wastewater. The suggested design achieves an exceptional treatment efficiency of 85.71% via MBBR technology.

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Based on the detailed design procedure and standard engineering guidelines, the required sizes of the various pre-treatment units are as follows:

- Screen Chamber: 1.32 m × 0.8 m
- Grit Chamber: 12 m × 3 m × 1.5 m
- Skimming Tank: 27 m × 27 m

All the calculated dimensions fall within the acceptable and recommended design ranges. Therefore, the proposed design is considered appropriate and technically sound for implementation

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