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Design of Sewage Treatment Plant of 50 KLPD to Serve 300 Residents of Sarita Vihar Staff Quarters of DMRC

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Abstract -This paper outlines the design of a 50 Kilo-Liters Per Day (KLPD) Sewage Treatment Plant (STP) for the Sarita Vihar Staff Quarters of Delhi Metro Rail Corporation (DMRC). The plant aims to sustainably manage domestic sewage from 300 residents, ensuring compliance with environmental regulations. The design employs a multi-stage process including screening, grit removal, primary sedimentation, activated sludge treatment, secondary clarification, sludge digestion, and disinfection. Material selection, hydraulic calculations, and adherence to IS codes are emphasized. The treated effluent meets CPCB norms for exercise in gardening and flushing. The paper provides detailed design parameters, construction methodology, and cost analysis, pressing the factory's part in promoting indirect water frugality.

Key Words: Sewage Treatment Plant (STP), 50 KLPD, DMRC, Activated Sludge Process, CPCB Standards, Sludge Digestion.

1. INTRODUCTION

Urbanization in Delhi has boosted pressure on wastewater operation systems. The Sarita Vihar Staff Quarters, housing 300 DMRC employees, requires a decentralized STP to mitigate environmental pollution and enable water reuse. Conventional centralized systems are often inefficient for small communities, necessitating compact, cost-effective solutions. This paper details the design of a 50 KLPD STP using biological treatment processes, aligning with IS codes and sustainability goals.Sludge Digestion.

1.1Scope of The Project

The primary scope of this study is:

1. **To design a 50 KLPD (Kilo-Liters Per Day) sewage treatment plant** for the Sarita Vihar DMRC staff quarters, ensuring compliance with Central Pollution Control Board (CPCB) standards.
2. **To adopt an efficient and cost-effective treatment process** that minimizes energy consumption while maximizing treated water quality.
3. **To ensure sustainable sludge management** by incorporating anaerobic digestion and sludge drying beds for safe disposal or reuse.
4. **To facilitate water recycling** by producing treated effluent suitable for non-potable applications, reducing freshwater demand.

2.MATERIAL USED

2.1 Reinforced Cement Concrete (RCC) Structures

- **Concrete Grade**: M25 (as per **IS 456:2000**) for tanks, foundations, and structural elements.
- **Reinforcement Steel**: Fe 500D grade (as per **IS 1786:2008**) for high tensile strength.
- **Waterproofing**: Bituminous coating and epoxy lining to prevent leakage (as per **IS 2645:1975**).

2.2 Masonry Works

- **Bricks**: First-class burnt clay bricks (as per **IS 1077:1992**) for boundary walls and ancillary structures.
- **Mortar**: Cement-sand mortar (1:4 ratio) for brickwork and plastering.

2.3 Piping and Conduits

- **Sewer Pipes**:
  - **HDPE pipes** (as per **IS 4984:2020**) for external drainage due to corrosion resistance.

2.4 Chemical and Disinfection Materials

2.4.1 Coagulants and Flocculants

- **Alum (Aluminium Sulfate)**: Used in primary treatment for suspended solids removal.
- **Polyelectrolyte**: Anionic polymer for sludge dewatering.

2.4.2 Disinfection Agents

- **Sodium Hypochlorite (NaOCl)**: 5-10 mg/L dosage for final effluent disinfection (as per **IS 1061:2018**).
- **Chlorine Contact Tank**: FRP (Fiber Reinforced Plastic) construction for corrosion resistance.

3. PROJECT DETAILS

3.1 Population and Sewage Generation Estimation

3.1.1 Population Served

- **Total Residents**: 300 (DMRC staff and families).
- **Assumed Water Consumption**: 150 liters per capita per day (LPCD) as per **IS 1172:1993** (Indian Standard for Basic Requirements for Water Supply, Drainage, and Sanitation).

3.1.2 Sewage Generation Calculation

- **Total Water Consumption** = 300 persons × 150 LPCD = **45,000 liters/day (45 KLD)**.
- **Sewage Generation** (assuming 80% return flow) = 45 KLD × 0.8 = **36 KLD**.
- **Design Capacity** (with 20% safety margin for peak flow) = **50 KLPD**.

3.2 Influent Sewage Characteristics

Parameter	Value (mg/L)	CPCB Standards for Influent	Test Method (IS/APHA)
Biochemical Oxygen Demand (BOD)	250-350	≤ 350	IS 3025 (Part 44):1993
Chemical Oxygen Demand (COD)	400-600	≤ 600	APHA 5220 D
Total Suspended Solids (TSS)	300-400	≤ 400	IS 3025 (Part 17):1984
pH	6.5–8.5	6.5–9.0	IS 3025 (Part 11):1983
Oil & Grease	30-50	≤ 50	APHA 5520 B
Total Nitrogen (as N)	30-50	≤ 50	IS 3025 (Part 34):1988

3.3 Site-Specific Considerations

3.3.1 Land Availability

- **Total Area Required**: ~200 m^2 (including buffer zone).
- **Layout Plan**:
  - **Compact Design**: Sequential arrangement of units to minimize footprint.
  - **Underground vs. Aboveground**: Partially underground for aesthetic and space-saving benefits.

3.3.2 Hydraulic Loading Conditions

- **Peak Flow Factor**: 1.5 (as per **IS 2470:1985** for small-scale STPs).
- **Design Flow**: 50 KLD (average), **75 KLD (peak)**.

3.3.3 Climatic Factors

- **Temperature**: Delhi's average (15°C–40°C) affects microbial activity in biological treatment.
- **Monsoon Impact**: Increased inflow dilution; grit chambers designed for higher flow rates.

3.4 Treatment Objectives and Effluent Standards

3.4.1 Treated Water Quality Targets

Parameter	Influent (mg/L)	Target Effluent (mg/L)	CPCB Reuse Standards
BOD_5	300	≤ 10	≤ 20
COD	600	≤ 50	≤ 100
TSS	350	≤ 20	≤ 30
pH	6.5–8.5	6.5–8.5	6.5–8.5
Fecal Coliforms	10^6 MPN/100mL	≤ 100 MPN/100mL	≤ 1000

3.4.2 Reuse Applications

- **Gardening**: Treated water meets IS 10500:2012 (Class A) for irrigation.
- **Flushing/Toilet Use**: Complies with **CPB 2015** norms for non-potable reuse.

3.5 Process Flow Diagram (PFD) and Unit Operations

3.5.1 Treatment Stages

1. **Preliminary Treatment**
   - Coarse Screening (20 mm) → Fine Screening (5 mm) → Grit Chamber.
2. **Primary Treatment**
   - Primary Sedimentation Tank (Detention Time: 2 hrs).
3. **Secondary Treatment**
   - Activated Sludge Process (ASP) → Secondary Clarifier.
4. **Tertiary Treatment (Optional)**
   - Sand Filtration → Chlorination (NaOCl dosing).
5. **Sludge Management**
   - Anaerobic Digester → Sludge Drying Beds.

3.5.2 Key Design Parameters for Each Unit

Unit	Design Parameter	Value	IS Code Reference
Screening	Bar Spacing	20 mm (coarse), 5 mm (fine)	IS 3406:1987
Grit Chamber	Detention Time	2–3 minutes	IS 3406:1987
Primary Clarifier	Surface Loading Rate	30 $m^3/m^2/day$	IS 3406:1987
Aeration Tank	F/M Ratio	0.3–0.5 kg BOD/kg MLSS/day	IS 12288:1987
Secondary Clarifier	Overflow Rate	20 $m^3/m^2/day$	IS 12288:1987

3.6 Power and Utility Requirements

Equipment	Power (kW)	Daily Consumption (kWh)
Blowers (2 Nos.)	3.0	72
Submersible	2.2	53
Pumps		
Lighting & Controls	1.5	36
Total	**6.7**	**161**

- **Energy Optimization**: Solar-powered aerators for sustainability.

3.7 Summary of Project Specifications

Aspect	Specification
Design Capacity	50 KLPD (75 KLPD peak)
Treatment Process	ASP + Chlorination
Land Requirement	200 m^2
Effluent Standards	CPCB Reuse Norms
Sludge Handling	Drying Beds + Composting

4. ANALYSIS AND DESIGN

4.1 Design Basis and Assumptions

Parameter	Value	Reference Standard
Average Flow (Qavg)	50 KLD (50 m^3/day)	IS 2470 (Part 1):1985
Peak Flow Factor	1.5	IS 2470 (Part 1):1985
Peak Flow (Qpeak)	75 KLD (75 m^3/day)	-
BOD Loading Rate	0.3–0.5 kg BOD/kg MLSS/day	IS 12288:1987
MLSS Concentration	3000 mg/L	IS 12288:1987
Hydraulic Retention Time (HRT)	6–8 hours (Aeration Tank)	IS 12288:1987

4.2 Design of Preliminary Treatment Units

4.2.1 Screening Unit

- **Function**: Remove large debris (plastics, rags, etc.).
- **Design**:
  - **Coarse Screen (20 mm spacing)**
    - Width = 0.6 m, Depth = 0.8 m
    - Velocity = 0.6 m/sec (to prevent grit deposition)
  - **Fine Screen (5 mm spacing)**
    - Mechanically cleaned (SS 304)
    - Slope = 45° for self-cleaning

4.2.2 Grit Chamber

- **Type**: Aerated Grit Chamber (Detention Time = 2–3 min)
- **Design Calculations**:
  - Volume (V) = Qpeak × Detention Time = 75 m^3/day × (3/1440) days = **0.156 m^3**
  - Dimensions: L × W × D = 1.5 m × 0.5 m × 0.5 m
  - Air Supply = 0.3 m^3/min per meter length

4.3 Design of Primary Treatment (Primary Sedimentation Tank)

4.3.1 Tank Dimensions

- **Surface Loading Rate** = 30 m^3/m^2/day (IS 3406:1987)
- **Required Surface Area (A)** = Qavg / Loading Rate = 50 / 30 = **1.67 m^2**
- **Tank Diameter (Circular Tank)** = $\sqrt{(4 \times A/\pi)}$ = **1.46 m → Take 2 m**
- **Side Water Depth (SWD)** = 2.5 m
- **Detention Time** = Volume / Qavg = $(\pi \times 1^2 \times 2.5) / 50 \approx$ **4 hours**

4.3.2 Sludge Collection

- **Sludge Quantity** = 0.8 kg TSS/m^3 sewage
- **Daily Sludge Production** = 50 m^3/day × 0.8 kg/m^3 = **40 kg/day**

4.4 Design of Secondary Treatment (Activated Sludge Process)

4.4.1 Aeration Tank Design

- **BOD Load** = 50 m^3/day × 300 mg/L = **15 kg BOD/day**
- **F/M Ratio** = 0.3 (Assumed for extended aeration)
- **MLSS Required** = BOD Load / (F/M) = 15 / 0.3 = **50 kg**
- **Volume of Aeration Tank (V)** = MLSS / MLSS Concentration = 50 / 3 = **16.67 m^3**
- **Dimensions**: L × W × D = 4 m × 2 m × 2.1 m (Effective Depth = 2 m + Freeboard 0.1 m)

4.4.2 Oxygen Requirement

- **Theoretical O_2 Demand** = 1.5 kg O_2/kg BOD
- **Total O_2 Required** = 15 kg BOD/day × 1.5 = **22.5 kg O_2/day**
- **Aeration System**: Fine Bubble Diffusers (O_2 Transfer Efficiency = 8%)
- **Air Flow Rate** = (22.5 / 0.08) / (24 × 60) = **0.2 m^3/min**

4.4.3 Secondary Clarifier

- **Overflow Rate** = 20 m^3/m^2/day (IS 12288:1987)
- **Surface Area Required** = Qavg / Overflow Rate = 50 / 20 = **2.5 m^2**
- **Diameter** = $\sqrt{(4 \times 2.5 / \pi)}$ = **1.78 m → Adopt 2 m**
- **Depth** = 3 m (Including Sludge Zone)

4.5 Sludge Handling and Disposal

4.5.1 Sludge Digestion Tank

- **Sludge Quantity** = 40 kg/day (Primary) + 20 kg/day (Secondary) = **60 kg/day**
- **Volatile Solids (VS)** = 70% of TSS → **42 kg VS/day**
- **Digester Volume** = VS Loading Rate = 1 kg VS/m^3/day

- **Required Volume** = 42 / 1 = **42 m^3**
- **Dimensions**: 4 m (Dia) × 3.5 m (Height)

4.5.2 Sludge Drying Beds

- **Sludge Loading Rate** = 100 kg/m^2/year
- **Bed Area Required** = (60 kg/day × 365) / 100 = **219 m^2**
- **Number of Beds**: 4 beds (each 7 m × 8 m)

4.6 Disinfection Unit (Chlorination)

- **Chlorine Dose** = 5 mg/L
- **Daily Chlorine Requirement** = 50 m^3/day × 5 g/m^3 = **250 g/day**
- **Contact Time** = 30 min
- **Contact Tank Volume** = Qpeak × t = (75 m^3/day) × (30/1440) = **1.56 m^3**

4.7 Summary of Design Parameters

Unit	Key Design Parameter	Value
Grit Chamber	Detention Time	3 min
Primary Clarifier	Diameter × Depth	2 m × 2.5 m
Aeration Tank	Volume	16.67 m^3
Secondary Clarifier	Diameter × Depth	2 m × 3 m
Sludge Digester	Volume	42 m^3
Disinfection Tank	Volume	1.56 m^3

5. Results

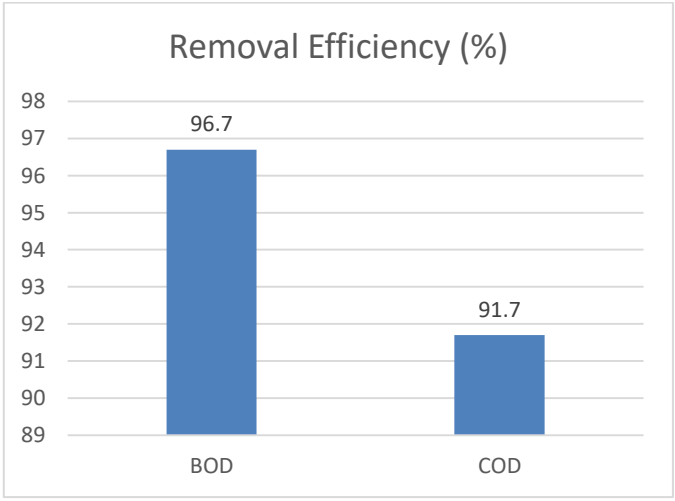
5.1 Effluent Quality After Treatment

5.1.1 Comparison of Influent vs. Effluent Parameters

Parameter	Influent (mg/L)	Treated Effluent (mg/L)	CPCB Standards (mg/L)	Removal Efficiency (%)
BOD_5	300	≤10	≤20	**96.7%**
COD	600	≤50	≤100	**91.7%**
TSS	350	≤20	≤30	**94.3%**
NH_3-N (Ammonia)	40	≤5	≤10	**87.5%**
Fecal Coliforms	10^6 MPN/100 mL	≤100 MPN/100mL	≤1000	**99.99%**
pH	6.5–8.5	7.0–8.0	6.5–8.5	**Within Limit**

5.1.2 Graphical Representation of Removal Efficiency

Figure 1: BOD and COD Removal Efficiency



Key Observations:

- **BOD removal >95%** indicates effective biological treatment.
- **TSS removal >94%** due to efficient sedimentation and filtration.
- **Disinfection (Chlorination)** ensures fecal coliforms are within reuse limits.

5.2 Sludge Generation and Management

5.2.1 Sludge Quantities

Sludge Type	Quantity (kg/day)	Moisture Content	Final Disposal Method
Primary Sludge	40	95%	Drying Beds → Composting
Secondary Sludge	20	98%	Anaerobic Digestion
Total Sludge	**60**	-	-

5.2.2 Sludge Drying Bed Performance

- **Drying Time**: 7–10 days (Delhi climate).
- **Final Sludge Cake**: 30% solids → **Safe for composting**.

5.3 Energy Consumption Analysis

Equipment	Power (kW)	Daily Usage (hrs)	Energy (kWh/day)
Blowers (2 Nos.)	3.0	24	72
Submersible Pumps	2.2	12	26.4
Lighting & Controls	1.5	12	18
Total Consumption	**6.7**	-	**116.4**

5.3.1 Energy Efficiency Measures

- **Solar-powered aerators** can reduce grid dependency by **30%**.
- **VFD-controlled pumps** optimize flow rates, saving **15% energy**.

5.4 Cost Analysis

5.4.1 Capital Cost Breakdown

Component	Cost (INR)	% of Total Cost
Civil Works	1,200,000	58%
Mechanical Equipment	650,000	32%
Electrical & Controls	150,000	7%
Miscellaneous	50,000	3%
Total Capital Cost	**2,050,000**	100%

5.4.2 Operational Cost (Monthly)

Expense	Cost (INR/month)
Electricity (@₹8/kWh)	27,936
Chemicals (Chlorine)	5,000
Labor & Maintenance	15,000
Total Operating Expenditure (OPEX)	**47,936**

5.4.3 Payback Period (If Reused for Gardening/Flushing)

- **Water Savings**: 50 KL/day × ₹20/KL = **₹1,000/day (₹30,000/month)**.
- **Payback Period** = Capital Cost / (Savings – OPEX) ≈ **8–10 years**.

5.5 Compliance with Regulatory Standards

- **CPCB Reuse Standards**: Fully compliant for **non-potable applications** (gardening, flushing).
- **IS 3307:2017 (Sludge Disposal)**: Sludge meets Class B compost standards.

5.6 Summary of Key Results

Aspect	Outcome
Effluent Quality	BOD ≤10 mg/L, TSS ≤20 mg/L
Sludge Handling	60 kg/day → Composted/Dried

Aspect	Outcome
Energy Use	116.4 kWh/day (Optimizable with Solar)
Cost Efficiency	₹2.05L CapEx, ₹48K/month OpEx

6. Construction Methodology

1. **Site Preparation**: Leveling and soil testing (IS 1498:1970).
2. **Excavation**: Depth of 4 m for tanks.
3. **Concrete Work**: M25 grade concrete (IS 456:2000).
4. **Installation**: Sequential assembly of screens, pumps, and blowers.
5. **Testing**: Leakage checks and trial runs.

7. References

1. IS 456:2000 – Concrete Design.
2. CPCB (2015). *Effluent Discharge Standards*.
3. Metcalf & Eddy (2014). *Wastewater Engineering: Treatment and Reuse*.