Design and Analysis of a Waste Water Treatment Plant in Chhalaila

A Development Engineering project (CP301) report submitted in partial fulfillment of the requirements for the award of the degree of

Bachelor of Technology

by

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Abstract

The water we use for showers, laundry, and sanitation doesn't simply disappear down the drain. Instead, it undergoes a multi-stage process to remove contaminants and transform it into a safe and reusable resource.

This project delves into the critical world of wastewater treatment. We will explore the methods of treating wastewater, from the removal of large solids to the breakdown of harmful bacteria. We did energy balance,material balance and equipment design of the various equipment involved in the wastewater treatment plant. Along with these calculations pertaining to the equipment, we also did the overall tentative costing for the establishment of the wastewater treatment plant.

Through the application of fundamental principles such as material balances, energy balances, and equipment design, we aim to develop an innovative and efficient treatment model tailored to our village's specific requirements.

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Chapter 1

Introduction to wastewater treatment

1.1 Introduction

Effective wastewater management is necessary for safeguarding public health and environmental sustainability particularly in rural areas, especially since proper wastewater management systems usually have not reached many villages yet.The project delves into the aspects of designing and implementing a wastewater treatment plant in Chhalaila village.

The rapid growth of population in Chhalaila together with farming activities have resulted in the generation of more wastewater which can be harmful to the local water sources and ecosystems if it finds its way there without being treated. This proposed plant seeks to address this by use of well thought out systems that take into account material as well as energy balances. By doing extensive analysis coupled with equipment selection, we try to establish a wastewater treatment plant with effectiveness, cost efficiency and ecological friendliness. The next sections give

FIGURE 1.1: Waste Water Management

an elaborate description of how the calculations were done, showing methodology used while calculating figures with reasons behind adoption of various treatment technologies during the design stage. This report acts as a guidance towards establishment of a sustainable wastewater treatment plant in Chhalalia; and acts as a general basis through which such systems can be established in other villages as well.

1.2 Background on wastewater treatment

Proper wastewater management is vital for environmental sustainability and public health. The volume of wastewater produced has increased considerably due urbanization and industrialization which are expanding across the world, thus creating problems for water resources and ecosystems. In general , the project of wastewater treatment is a key initiative that shows dedication to environmental care , continuity in development and well-being of current and future generations . Collaborative efforts and innovative solutions with regard to wastewater are what this project is all about .

1.3 Problem Statement

Developing a wastewater purification system that is both efficient and can last for years. It should be eco-friendly, help mitigate issues like removal of harmful substances from the water, optimize the amount of energy used, and also enhance equipment design.

1.4 Need for study

To protect the environment, our health and vital resources, we must understand wastewater treatment well. With good wastewater treatment processes in place, pollutants cannot seep into our rivers and lakes thus protecting aquatic ecosystems as well as biodiversity. Besides, it stops any harmful pathogens or contaminants that would otherwise have made us sick due to raw sewage. In addition, the recovery and reuse of valuable resources such as nutrients and energy are enabled through the treatment of wastewater, which promotes sustainability and diminishes the pressure on limited resources. It's necessary to obey the rules set for wastewater disposal just as it's vital to come up with unorthodox ways of treating it to deal with both water shortage and changes in temperature more so resilience.

1.5 Study Objectives

The main aim of our project is optimizing wastewater treatment systems in a comprehensive manner. To do this, we will balance energy and mass with design assessments of equipment thereby improving process efficiency that is sustainable. We hope to understand how energy works, measure how much stuff moves around (mass flow quantification), assess equipment performance (evaluation), bring everything together (findings integration), make strategies for optimizing systems (optimization strategies devising), and appraise both ecological and economic implications.

1.6 Summary

The wastewater treatment project will enhance its efficiency and effectiveness through the integration of energy balance, mass balance, and equipment design considerations. By taking a comprehensive approach, the project aims at pinpointing energy inputs, usage patterns, and optimization opportunities that exist within the treatment system for it to be better than before. By tracking the flow path of pollutants, nutrients and other substances through the analysis of mass balance, this project aims at ensuring their effective removal, as well as exploration of opportunities for resource recovery. Equipment's design is guided by knowledge from energy and mass balances assessments with emphasis on choosing technologies that would ensure optimal treatment performance with the smallest environmental damage possible.

Chapter 2

Literature Review

2.1 Overview of existing literature on wastewater treatment

Following is an overview of existing literature related to wastewater treatment plants, material balances, energy balances, equipment design, and costing.

Wastewater Treatment Plants:

- Wastewater treatment plant design, operation, optimization, and environmental impact are all things that we may find in the literature right now.
- A variety of processes for treating wastewater have been studied previously through physical, chemical and biological methods to remove pollutants from wastewater.

Material Balances:

- Literature on material balances in wastewater treatment plants typically discusses the input-output relationships of various substances in the treatment process.
- Research often aims to optimize material flows, minimize losses, and improve overall treatment efficiency.[1]

Energy Balances:

- Existing literature on energy balances in wastewater treatment plants examines the energy consumption, generation, and efficiency of the treatment processes. [2]
- Research often aims to reduce the carbon footprint and operational costs of wastewater treatment plants through energy optimization.

Equipment Design:

- Literature on equipment design for wastewater treatment plants covers the selection, sizing, and operation of various treatment units and components. [3]
- Studies may discuss the design criteria, performance evaluation, and maintenance considerations for equipment like pumps, reactors, filters, and separators.

Costing:

- Existing literature examines the costs involved in wastewater treatment facilities. This includes research on initial construction expenses, ongoing operational costs, life cycle analysis, and evaluating costs against benefits.[3]
- Research may explore cost estimation methods, economic evaluation criteria, and financial models for wastewater treatment projects.

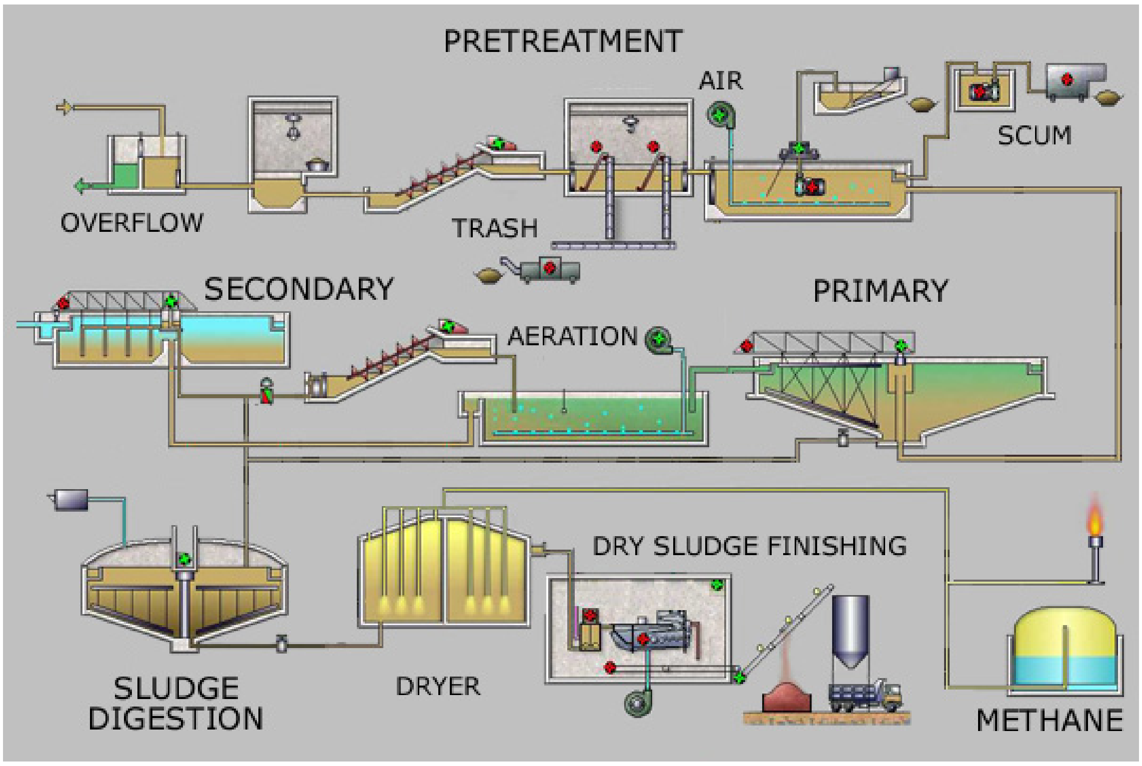

FIGURE 2.1: WasteWater Treatment Process

2.2 Detailed review of each process/component

- **Screening Equipments:** The literature discusses the use of screening equipment like bar screens, coarse screens, and fine screens to remove large solids, debris, and other materials from the influent wastewater. Studies have shown that screening can remove up to 50% of total suspended solids (TSS) and 30% of biochemical oxygen demand (BOD) from the wastewater. [4]

- **Primary Treatment:**Primary treatment typically involves sedimentation tanks or clarifiers to remove suspended solids, oil, and grease through physical settling. Research indicates that primary sedimentation can remove 50-70% of TSS and 20-30% of BOD from the wastewater. [5]

- **Secondary Treatment:** Biological secondary treatment processes like activated sludge, trickling filters, and membrane bioreactors are widely studied in the literature. These processes can achieve 85-95% removal of BOD and TSS. [6]

- **Tertiary Treatment:** Advanced tertiary treatment methods discussed in the literature include chemical precipitation, adsorption, membrane filtration, and advanced oxidation. These can further remove nutrients, pathogens, and emerging contaminants like microplastics with high efficiency. [7]

- **Disinfection:** The disinfection of potable water and wastewater provides a degree of protection from contact with pathogenic organisms including those causing cholera, polio, typhoid, hepatitis and a number of other bacterial, viral and parasitic diseases. Disinfection is a process where a significant percentage of pathogenic organisms are killed or controlled. [8]

- **Sludge Treatment:** The residue that accumulates in sewage treatment plants is called sludge (or bio solids). Sewage sludge is the solid, semisolid, or slurry residual material that is produced as a by-product of wastewater treatment processes. [9]

2.3 Discussion of challenges, best practices, and emerging technologies in wastewater treatment

In wastewater treatment, material balance, equipment design and energy balance are the core areas of concern. However, it is accompanied by some problems that have not been solved yet and new techniques as well as best practices. The major task is to maintain a balance in the quantity of different contaminants, nutrients and solid matter present in the waste water stream because the composition of influent changes frequently. Energy consideration should be given utmost priority while still using this traditional methods which require massive amounts of energy for instance aeration among others that involves pumping too. Designing efficient treatment machines on the other hand need more attention paid to hydraulic residence time; mixing efficiency process kinetics etc. so that they can perform optimally.

The most effective way to deal with these issues according to the currently established norms is by incorporating advanced treatment processes into existing infrastructure which will lead to better overall performance. This can be achieved through changing various processes involved in order to use less power during operations or coming up with creative designs for devices that do not consume much power but still work effectively in treating waste water. Furthermore, adding resource recovery measures into any treatment system would help meet sustainability targets while at the same time improving economic feasibility of such facilities.

New technologies provide solutions for tackling these challenges as well as optimizing wastewater treatment

2.4 Future directions in the field

Upcoming waste water management schemes are expected to give more attention to improving material and energy balances as well as designing efficient facilities. Advanced technologies such as resource recovery systems and membrane bioreactors will be heavily relied on in this course. In order to ensure sustainability and cost-effectiveness, there will be a need for energy-saving methods and creative equipment designs.

Chapter 3

Study Methodology

3.1 Detailed Description of Methodology

The project aims to design a treatment plant to meet the water needs of **Chalaila village in Patiala**. The primary objective is to provide clean and safe drinking water to the residents while also considering potential agricultural or industrial water requirements. Additionally, the project seeks to improve overall water quality in the area and ensure compliance with regulatory standards.

For this we attempt to design a **Waste Water Treatment Plant(WWTP)** theoritically, using our knowledge of Material Balance,Energy Balance & Equipment Design and from a detailed literature review.

We design a **Process Flow Diagram**, based on the literature review, devide it in various processes such as:

- Screening Processes
- Primary Treatment

- Secondary Treatment
- Tertiary Treatment
- Disinfection
- Sludge Treatment
- Storage

For each of the processes involved equipments were chosen and we did its design, their Material & Energy balance. Finally we did a basic cost analysis.

3.2 Data Collection Methods

An analysis on multiple villages done by **Punjab Government** revealed crucial information regarding water requirements in these villages. For the Chalaila village all data containing information such as Demographic data, including population size, provided insights into current water demand. Existing water sources, such as groundwater, surface water, or recycled water, were identified to understand the available resources. Water quality parameters, including pH, turbidity, dissolved solids, microbial contamination, and specific pollutants, were assessed to gauge the quality of the water sources.

The waste stabilization pond at this village is a single-chambered system covering a total area of 3404 square meters with an approximate depth of 6 meters. This configuration results in a total effective volume of **20424 cubic meters**.

Before entering the waste stabilization pond, the wastewater from the village undergoes a preliminary treatment process. It first passes through a coarse screen to

Sr. No.	Point of sample collection	Concentration of pollutants of the wastewater sample collected on 23.01.2019		Concentration of pollutants of the wastewater sample collected on 06.02.2019		Concentration of pollutants of untreated wastewater directly entering into the pond on 22.2.2019	
		Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
1.	pH	7.81	7.71	7.56	7.65	7.73	7.8
2.	COD mg/l	400	198	242	212	868	785
3.	BOD mg/l	184	86	102	87	181	108
4.	TSS mg/l	160	92	74	58	176	92
5.	Faecal Coliform MPN/100 ml	2,80,000	1,10,000	1,40,000	46,000	1,40,000	43,000

FIGURE 3.1: Analysis results of wastewater collected on 23.1.2019, 6.2.2019 and 22.2.2019 from WSP in Village Chalalila

remove large debris. Following this, it goes through a series of three circular tanks with tangential entry.

With a village population of approximately **2835 persons**, the wastewater generated amounts to about **284 kiloliters per day (KLD)**. We rounded it to **300 KLD** for our use. As a result, the hydraulic retention time (HRT) of this waste stabilization pond is 72 days.

The waste stabilization pond is constructed with earthen material and lined from all sides to prevent seepage. Once treated, the wastewater flows through gravity and is utilized for irrigation purposes on agricultural land.

3.3 Equipment Selection Criteria

The selection of equipments for various processes depends upon a lot of factors including water flow rate into the system, waste water composition, its pH, TSS, etc. Since our system has low water flow rate of about 300 KLD and properties of

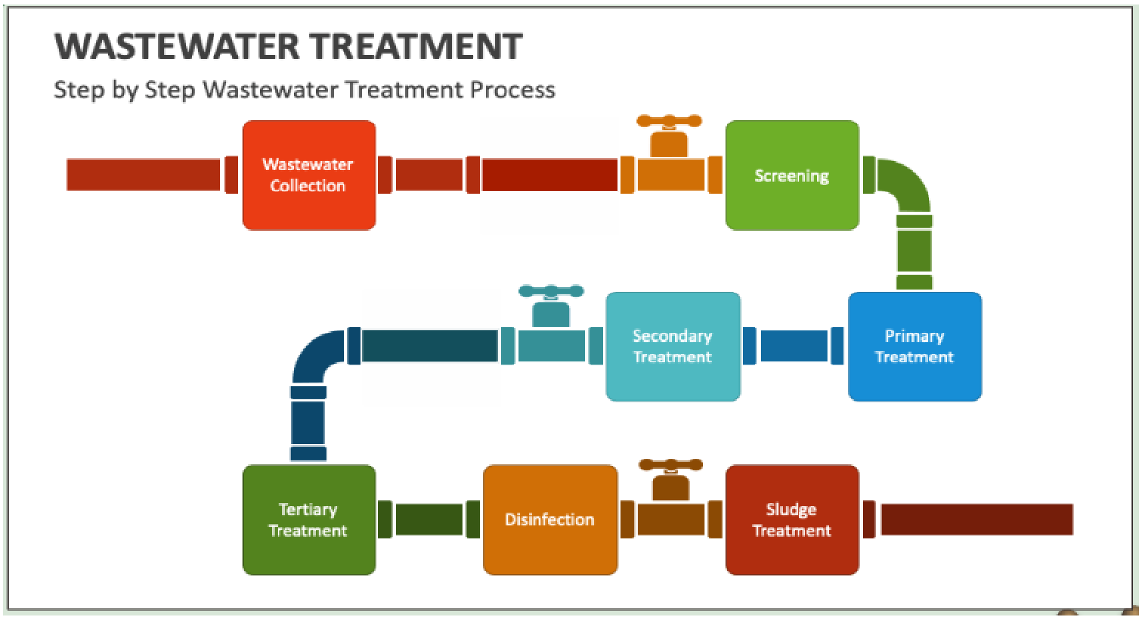

FIGURE 3.2: WWTP Block Diagram

water was already determined from reports, the volume and design of equipments was chosen as such to minimize any losses while maximizing the yield.

3.4 Process Flow Diagrams

To eliminate the contaminants it contains, the water that enters WWTPs goes through a number of physical, chemical, and biological processes. The four stages of these procedures are commonly referred to as preliminary, **primary, secondary, and tertiary treatments**. There is generally a pre-treatment stage before these main processes which includes **Bar Screening** & **Grit Removal** .

WWTPs additionally perform additional procedures related to the byproducts acquired from the various treatments. Some of these procedures, like the handling and treatment of sludge, are noteworthy due to their complexity and high level of interest.

Mass Balance Process Flow Diagram:

3.5 Equipment Calculations

3.5.1 Screening Equipments

Screening equipment plays a crucial role in wastewater treatment plants by removing large solids and debris from the incoming wastewater stream before it enters subsequent treatment processes.

3.5.1.1 Bar Screening

Bar screens capture large debris like plastics and rags at the inlet, preventing clogs and damage to equipment.

Equipment Design: By Kirshner's Eq.:

$$H = \beta \left(\frac{W}{b} \right) h_v Sin\theta \tag{3.1}$$

β = 2.42 (for sharp edge rectangular bar)

W = width of bar(m)

b = clear spacing(m) [bar screens have a 0.64 to 2.54 cm clear spacing]

Inclination for Mechanical Process : 60° - 90°

We take : 60°

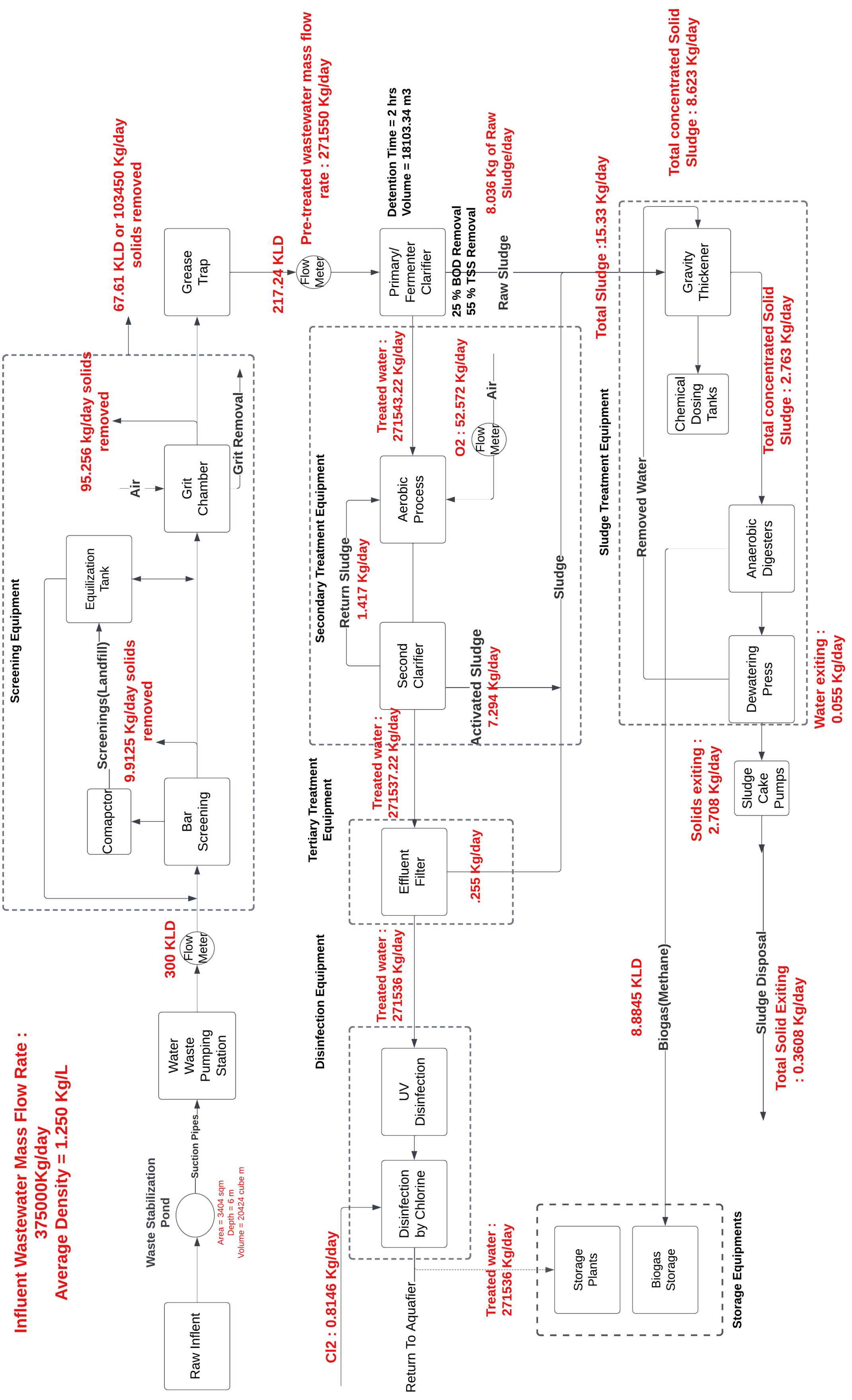

FIGURE 3.3: Mass Balance

FIGURE 3.4: Bar Screening

Velocity range : 0.3 - 1.2 m/s

We take : 0.4 m/s

Velocity head of approaching rack $(h_v) = \frac{V_a^2}{2g}$

$h_v = 0.0081m$

Let. Bar Dimensions be: 1 x 5 cm

= 0.01 x 0.05 m (W x L)

H = 0.0353 m

Energy Required : 3Hp

: **2.24 kWh / day**

Material Balance:

$$\text{TSS} = 58\,\text{mg/liter}$$

$$\text{BOD} = 87\,\text{mg/liter}$$

$$\text{COD} = 212\,\text{mg/liter}$$

$$\text{pH} = 7.65$$

$$Q_{\text{out}} = 211.85\,\text{KLD} = 0.00245\,\text{m}^3/\text{s}$$

Solids:

$$\text{Solids in}: Q_{\text{in}} \times \text{Influent TSS} = 22200\,\text{g/day}$$

$$\text{Solids out}: Q_{\text{out}} \times \text{Effluent TSS} = 12287.5\,\text{g/day}$$

$$\text{Solids removed}: \ \mathbf{9912.5\,g/day}$$

Q**: KLD**

TSS: mg/L

Energy Balance :

$$
\begin{aligned}
Q &= 300\,\text{KLD} = 0.0034\,\text{m}^3/\text{s} \\
\text{Spacing between bars (b)} &= 0.025\,\text{m} \\
\text{Inclination for Mechanical Process} &= 60^\circ \\
\text{Velocity } (\text{V}_a) &= 0.4\,\text{m/s} \\
\text{Depth/Width ratio} &= 1.5\,(\text{for an efficient section}) \\
W &= 0.075\,\text{m} \\
d &= 0.1129\,\text{m} \\
L &= 2\,\text{m} \\
H &= 0.0353\,\text{m} \\
\text{Head loss} &= .053 \\
\text{Velocity } (\text{V}_b) &= 0.248\,\text{m/s} \\
\text{Cross-sectional Area } (\text{A}_s) &= \frac{A}{Sin\theta} \\
\text{Net area available for flow} &=_s \cdot \frac{b}{b + t_bar} \\
\text{Number of bars (n)} &= .t_bar + (n-1)b = W \\
&= 2.83 = 3(approx)
\end{aligned}
$$

3.5.1.2 Grit Removal

Grit removal systems eliminate heavier solids such as sand and gravel to protect pumps and pipes from abrasion.

FIGURE 3.5: Grit Removal

Equipment Design: Given parameters:

- Velocity in grit chamber, $V_b = 0.248$ m/s
- Flow rate out, $Q_{\text{out}} = 0.00245$ m^3/s
- Detention Time, $t = 1$ min $= 60$ s
- Additional length for inlet and outlet zones, $1.25 \times L = 18.75$ m
- Total depth including freeboard and grit accumulation, 0.116 m + 0.15 m + 0.05 m = 0.316 m

Calculations:

- Length of grit chamber: $L = \frac{18.75\text{ m}}{1.25} = 15$ m
- Volume of grit chamber: $V = Q_{\text{out}} \times t = 0.00245\text{ m}^3/\text{s} \times 60\text{ s} = 0.147\text{ m}^3$
- Cross-sectional area of grit chamber: $A = \frac{V_b}{L} = \frac{0.248\text{ m/s}}{15\text{ m}} \approx 0.0165\text{ m}^2$
- Width and depth of grit chamber: 0.116 m (assuming 1:1 ratio)

Dimensions of the grit chamber: 18.75 m $\times$ 0.116 m $\times$ 0.316 m (Length $\times$ Width $\times$ Height)

These calculations provide the necessary dimensions and flow characteristics for designing the grit removal equipment.

Material Balance :

Given influent and effluent parameters:

- Influent flow rate: $Q_{\text{in}} = 0.00245\ \text{m}^3/\text{s} = 211.68\ \text{m}^3/\text{day}$
- Influent grit concentration: 500 mg/L
- Effluent grit concentration: 50 mg/L

Calculations:

- Influent Grit Load: $Q_{\text{in}} \times$ Influent Grit Concentration $= 211.68\ \text{m}^3/\text{day} \times 500\ \text{mg/L} = 105.84\ \text{kg/day}$
- Effluent Grit Load: $Q_{\text{out}} \times$ Effluent Grit Concentration $= 211.68\ \text{m}^3/\text{day} \times 50\ \text{mg/L} = 10.584\ \text{kg/day}$
- Grit Removed by Settling: Influent Grit Load$-$Effluent Grit Load $= 105.84\ \text{kg/day} - 10.584\ \text{kg/day} = 95.256\ \text{kg/day}$

This material balance provides insights into the effectiveness of grit removal based on the specified concentrations and flow rates.

Energy Balance:

Given parameters:

- Aeration time: 60 sec
- Energy required: 0.6 kWh/m^3 of water treated
- Energy used: 127 kWh/day

Calculations:

- Total water treated per day: $Q_{\text{in}} = 211.68\ \text{m}^3/\text{day}$
- Total energy consumption per day: 127 kWh/day
- Energy per unit volume of water treated: 0.6 kWh/m^3

Energy Balance Equation:

$$\text{Total Energy Used} = \text{Energy per unit volume} \times \text{Total water treated per day}$$

Substituting the values:

$$127\ \text{kWh/day} = 0.6\ \text{kWh/m}^3 \times 211.68\ \text{m}^3/\text{day}$$

Solving for the total water treated:

$$\text{Total water treated per day} = \frac{127\ \text{kWh/day}}{0.6\ \text{kWh/m}^3} \approx 212.8\ \text{m}^3/\text{day}$$

This energy balance calculation shows the relationship between energy consumption and water treatment volume.

Equipment Design:

Given parameters for equipment design:

3.5.1.3 Equalisation Tank

Equalization tank regulate variations in flow rate and pollutant concentrations to ensure consistent and efficient treatment downstream.

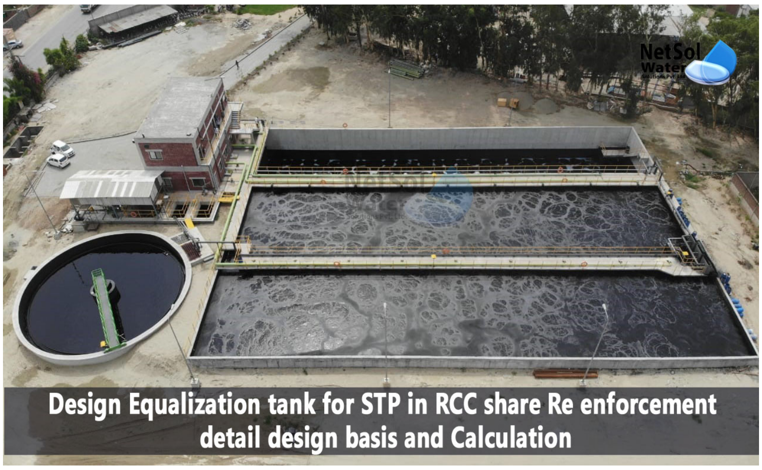

FIGURE 3.6: Equalization Tank

- Detention Time: 3 hours (or 10800 seconds)
- Flow rate: $Q = 0.0034\ \mathrm{m^3/s}$

Calculations:

- Volume of equalization tank: $V = Q \times t = 0.0034\ \mathrm{m^3/s} \times 10800\ \mathrm{s} = 36.72\ \mathrm{m^3}$

Dimensions of the equalization tank:

- Length (L): 4 m
- Width (B): 3.5 m
- Height (H): 2.6 m

Therefore, the equalization tank can be designed with dimensions 4 **m** × 3.5 **m** × 2.6 **m** (Length × Width × Height).

Note: An equalization tank may not be necessary for low flows, depending on the specific treatment requirements and variations in influent flow rates and pollutant concentrations.

3.5.1.4 Compactor

A compactor compresses solid waste material, often used in wastewater treatment to condense sludge. It reduces volume for easier disposal or processing.

FIGURE 3.7: Compactor

3.5.1.5 Grease Trap

A grease trap, also known as a grease interceptor or grease separator, is a device used in wastewater treatment systems to prevent fats, oils, and grease (often referred to as FOG) from entering the sewer system.

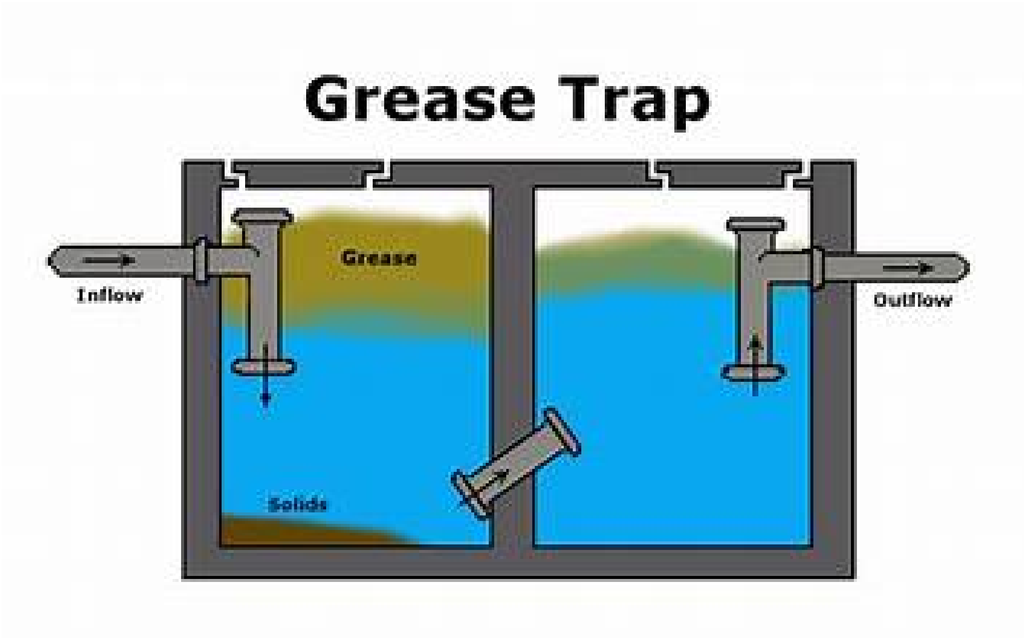

FIGURE 3.8: Grease Trap

3.5.2 Primary Treatment

3.5.2.1 Primary Fermenter/Clarifier

Purpose: The primary fermenter serves as a tank or vessel for the initial treatment of wastewater.

Process: It allows solid materials, including large particles, debris, and organic matter, to settle out of the wastewater.

Settling Mechanism: The primary fermenter facilitates settling by providing sufficient retention time for solids to settle to the bottom.

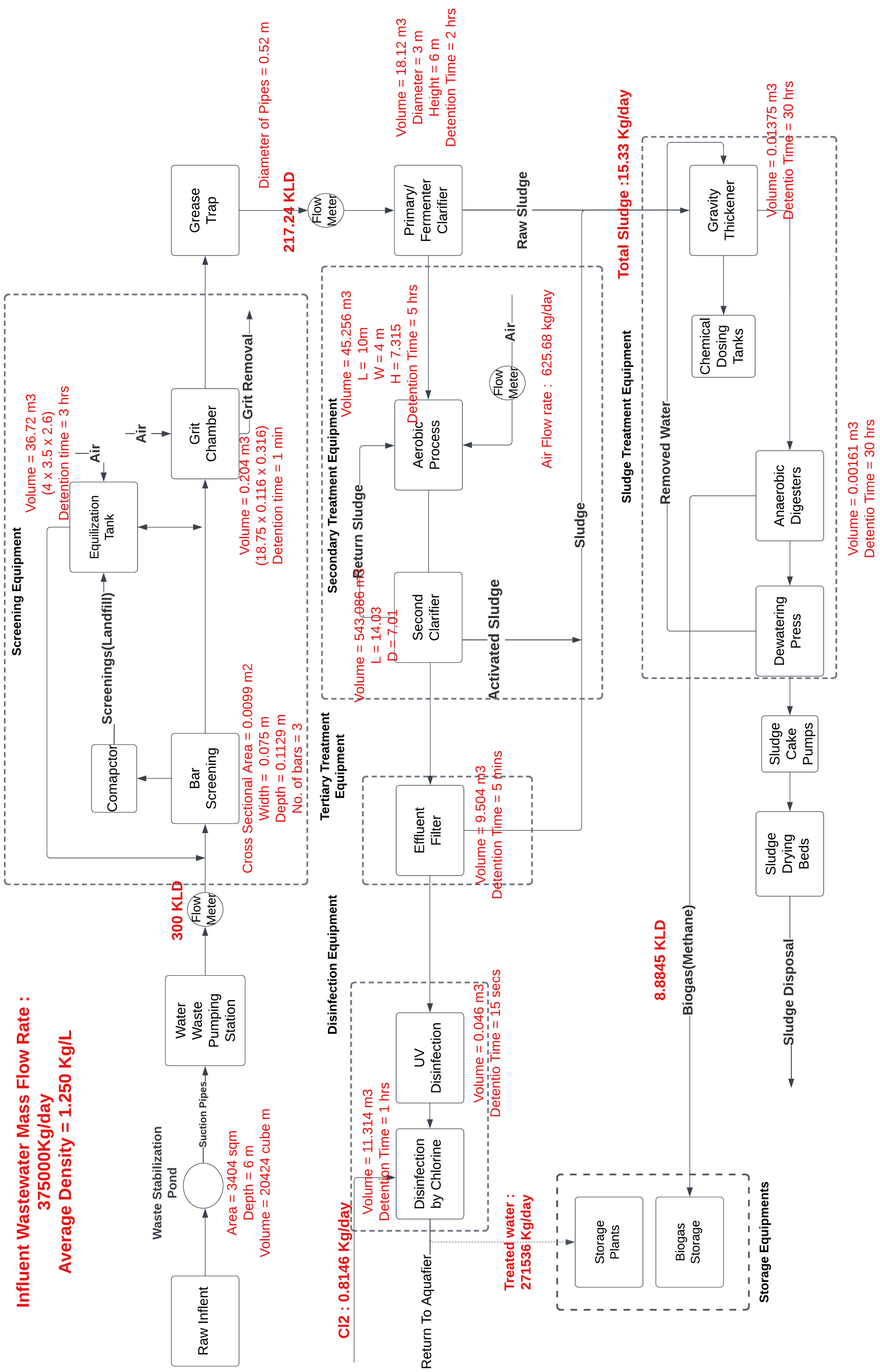

Figure 3.9: Equipment Design

Equipment Design:

$$\text{Flow rate} = 271550\,\text{Kg/Day}$$
$$\text{Detention time} = \frac{2}{24}\,\text{Days}$$
$$\text{Density of Liquid being clarified} = 1250\,\text{Kg/m}^3$$
$$L/D = 2$$
$$\mathbf{V = 18.12\,m^3}$$
$$\mathbf{L = 6\,m}$$
$$\mathbf{D = 3\,m}$$

The tank volume V can be calculated using the formula:

$$V = \frac{\text{Flow Rate} \times \text{Detention Time}}{24 \times \text{Density}}$$

Substituting the given values, we get:

$$V = \frac{271550 \times \frac{2}{24}}{24 \times 1250}$$

Solving for V, we find:

$$\mathbf{V\ =\ 18.12\,m^3}$$

Material Balance: Given:

$$\begin{aligned}
\text{Detention time} &= 2\,\text{hours} \\
V &= 18.12\,\text{m}^3 \\
\text{BOD \% removal} &= 25\% \\
\text{Inlet BOD (87 mg/liter in mass)} &= 22168.489\,\text{g/day} \\
\text{Remaining BOD} &= 16625.869\,\text{g/day} \\
\text{TSS \% Removal} &= 55\% \\
\text{TSS removed} &= 6929.956\,\text{g/day} \\
\text{TSS remaining} &= 5669.96\,\text{g/day} \\
\text{Sludge production coefficient} &= 0.2 \times 5669.96 \\
&= 1107.924\,\text{g/day} \\
\textbf{Treated Water mass Rate} &= \mathbf{271550\,kg/day} \\
\textbf{Water left} &= \mathbf{271543.22\,kg/day}
\end{aligned}$$

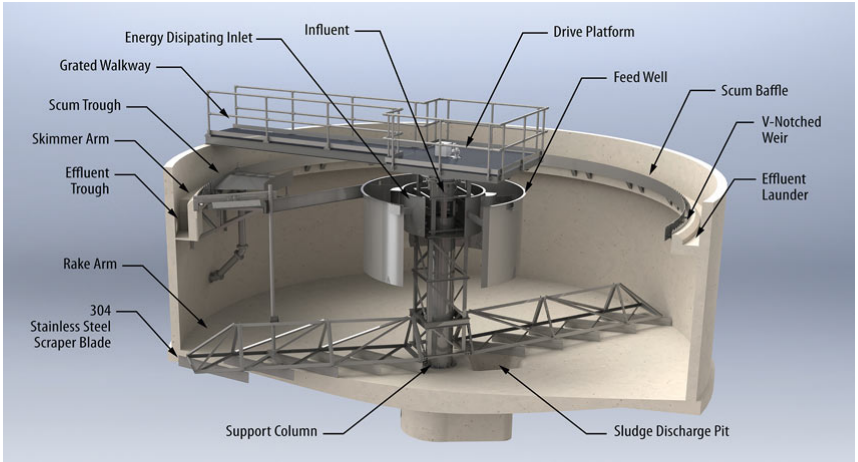

FIGURE 3.10: Primary Clarifier

Energy Balance: Given:

$$
\begin{aligned}
\text{Batch size (volume processed)} &= 18.12\,\text{liters} \\
\text{Density of fermenting mixture} &= 1250\,\text{kg/m}^3 \\
\text{Operating time per batch} &= 2\,\text{hours} \\
\text{Assumptions:} & \\
\text{Power consumption of mixing mechanism} &= 5\,\text{kW} \\
\text{Power consumption of inlet and outlet pumps} &= 3\,\text{kW each} \\
\text{Energy consumption (mixing)} &= 10\,\text{kWh per batch} \\
\text{Energy consumption (pumps)} &= 6\,\text{kWh per batch} \\
\textbf{Total Energy Required} &= 13 \times 12 \\
&= \mathbf{264\,kWh/day}
\end{aligned}
$$

3.5.3 Secondary Treatment

3.5.3.1 Aerobic Process

Conversion Process: Aerobic treatment breaks down organic pollutants into CO_2 and H_2O.

Microbial Action: Aerobic bacteria and microorganisms use oxygen to oxidize organic compounds.

Objective: Goal is to degrade organics, enhancing water quality.

Oxygen Dependence: Oxygen enables efficient breakdown of organic matter.

Material Balance for Aeration Tank:

Given parameters for the aeration tank:

- Flow rate: $Q = 217.24\ \text{m}^3/\text{day}$
- Chemical Oxygen Demand (COD): 242 mg/liter
- Aeration time: 24 hours/day

Calculations:

- Oxygen required per day:

$$\text{O}_2\ \text{required} = \text{Flow Rate} \times \text{COD} = 217.24\ \text{kL/day} \times 242\ \text{mg/liter} = 52572\ \text{g/day}$$

- Oxygen demand rate per hour:

$$\text{O}_2\ \text{demand rate} = \frac{\text{O}_2\ \text{required}}{\text{Aeration time}} = \frac{52572\ \text{g/day}}{24\ \text{hours/day}} = 2190.5\ \text{g/hour} = 2.190\ \text{kg/hour}$$

- Oxygen transfer efficiency of fine bubble diffuser (submerged to 20 feet): 40%
- Required Oxygen Flow Rate:

$$\text{Required Oxygen Flow Rate} = \frac{\text{O}_2 \text{ demand rate}}{\text{Oxygen Transfer Efficiency}} = \frac{2.190 \text{ kg/hour}}{0.40} = 5.475 \text{ kg/hour}$$

- Oxygen concentration in air (typically 21%):
- Required Air Flow Rate:

$$\text{Required Air Flow Rate} = \frac{\text{Required Oxygen Flow Rate}}{0.21} = \frac{5.475 \text{ kg/hour}}{0.21} \approx 26.07 \text{ kg air/hour}$$

Therefore, the aeration tank requires approximately 5.475 kg/hour of oxygen, which corresponds to approximately 26.07 kg/hour of air flow rate (assuming 21% oxygen concentration in air).

Equipment Design:

Given parameters for the aeration tank:

- Flow rate: $Q = 217.24$ kL/day = 293.76 m^3/day
- Aeration time: 24 hours/day

Calculations for Aeration Tank Volume:

- Volume of aeration tank:

$$\text{Volume} = \text{Flow rate} \times \text{Aeration time} = 293.76 \text{ m}^3/\text{day} \times 24 \text{ hours} = 7058.24 \text{ m}^3$$

Dimensions of the aeration tank:

- Height (H): 20 feet + 20% = 7.315 meters
- Length (L): 10 meters
- Width (W): 4 meters

Considering a rectangular aeration tank with a length of 10 meters and a width of 4 meters (L/D ratio = 2.5), the dimensions are:

$$\textbf{Dimensions: } 10\text{ m} \times 4\text{ m} \times 7.315\text{ m (L} \times \text{ W} \times \text{ H)}$$

Therefore, the aeration tank is designed with a rectangular shape, suitable for efficient aerobic treatment based on the specified dimensions and volume requirements.

3.5.3.2 Secondary Clarifier

Role: Secondary clarifiers are vital in wastewater treatment plants, especially post-primary treatment.
Focus: They target dissolved and suspended biological matter after primary treatment.
Process: Clarification methods, like sedimentation or flocculation, separate remaining solids from treated water.
Outcome: Enhances water quality by effectively removing biological contaminants.

Equipment Design:

Given parameters for the secondary clarifier:

- Detention time: 2 - 3 hours
- Mass flow rate: 271543.2 kg/day
- Volume flow rate: 217.23 m^3/day (assuming density = 1250 kg/m^3)
- Detention time: Volume / Flow rate = 543.075 m^3 (assuming 2.5 hours as detention time)
- L/D ratio: 2

Calculations for Secondary Clarifier Dimensions:

- Length (L): 14.03 m
- Diameter (D): 7.01 m

Therefore, the dimensions of the secondary clarifier are
14.03 m × 7.01 m (L/D ratio = 2).

Material Balance:

Given efficiency: 70%

- Activated sludge removal: 70% of 5669.76 g/day = 3968.97 g/day
- Remaining TSS (Total Suspended Solids): 1700 g/day
- 20% return sludge: 1417 g/day
- Remaining TSS: 283.79 g/day
- Water remaining: 271537.22 kg/day

Energy Balance:

Given parameters:

- Motor Rating (P_{motor}): 5 kW (Typically ranges from 5 to 20 kW for medium-sized secondary clarifier)
- Operational Time (t): 24 hours/day
- Power for sludge recirculation: 10 kW (Typically ranges from 10 to 100 kW)

Calculations:

- Energy used for motor: $P_{\text{motor}} \times t = 5 \text{ kW} \times 24 \text{ hours/day} = 120 \text{ kWh/day}$
- Energy used for sludge recirculation: $10 \text{ kW} \times 24 \text{ hours/day} = 240 \text{ kWh/day}$
- Total Energy required: $120 \text{ kWh/day} + 240 \text{ kWh/day} = 360 \text{ kWh/day}$

Therefore, the total energy required for the secondary clarifier operation is 360 kWh/day.

3.5.4 Tertiary Treatment

3.5.4.1 Effluent filter

- **Function:** Effluent filters capture solid particles from wastewater as it flows through.
- **Materials:** Typically constructed from plastic or stainless steel.
- **Design:** Features a fine mesh or screen that traps particles while allowing liquid to pass through.

Equipment Design:

$$\text{TSS Removed} = 0.255\,\text{Kg/day}$$
$$\text{Water Out} = 271536\,\text{kg/day}$$
$$\text{Required Volume of Effluent Filter} = 9.504\,\text{m}^3$$

Material Balance: Assuming 90% efficiency:

$$\begin{aligned}
\text{TSS removal} &= 0.9 \times 283.75 \\
&= 255.375\,\text{g/day} \\
\text{TSS remaining} &= 28\,\text{g/day} \\
\text{Water remaining} &= 271536\,\text{kg/day} \\
\text{TSS Removed} &= 0.255\,\text{Kg/day} \\
\text{Water Out} &= 271536\,\text{kg/day}
\end{aligned}$$

Energy Balance: The energy consumption (P) can be estimated using the motor rating and operational time. Additionally, some filter designs might use pressurized

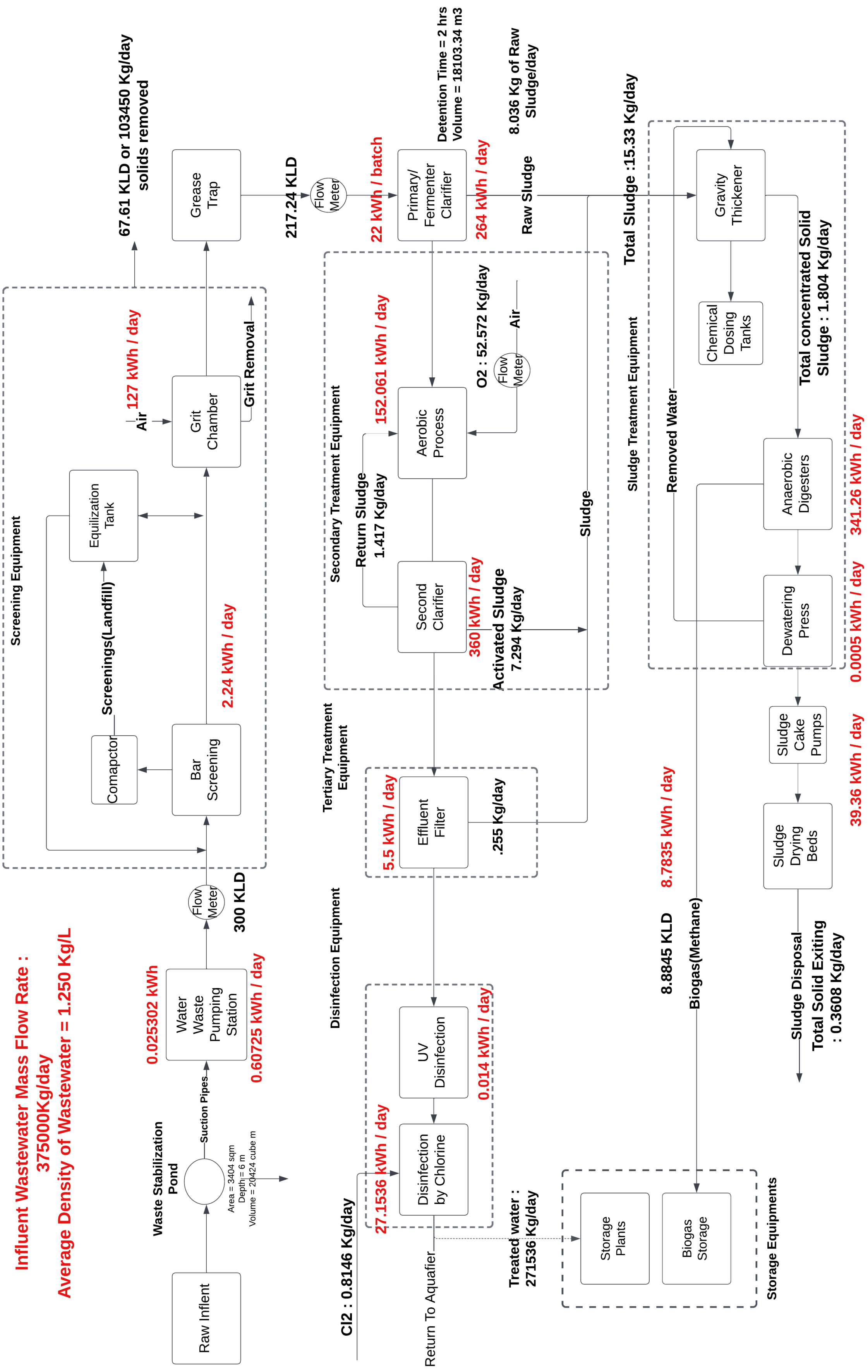

Figure 3.11: Energy Balance

FIGURE 3.12: Effluent filter

air for cleaning. Assume:

$$\text{Backwash motor rating } (\mathrm{P_{motor}}) = 0.5\,\mathrm{kW}$$

$$\text{Backwash operation time } (\mathrm{t_{backwash}}) = 1\,\mathrm{hour/day}$$

$$\text{Compressed air energy consumption } (\mathrm{P_{air}}) = 5\,\mathrm{kWh/day}\ \text{(assumed value)}$$

$$\begin{aligned} P &= P_{\text{motor}} \times t_{\text{backwash}} + P_{\text{air}} \\ &= 0.5\,\mathrm{kW} \times 1\,\mathrm{hour/day} + 5\,\mathrm{kWh/day} \\ &= 5.5\,\mathrm{kWh/day} \end{aligned}$$

Total Energy Required: 5.5 kWh/day

3.5.5 Disinfection Equipments

3.5.5.1 UV disinfection

A UV disinfection filter, in the context of wastewater treatment, is a technology that utilizes ultraviolet (UV) light to kill or deactivate pathogens and microorganisms present in wastewater.

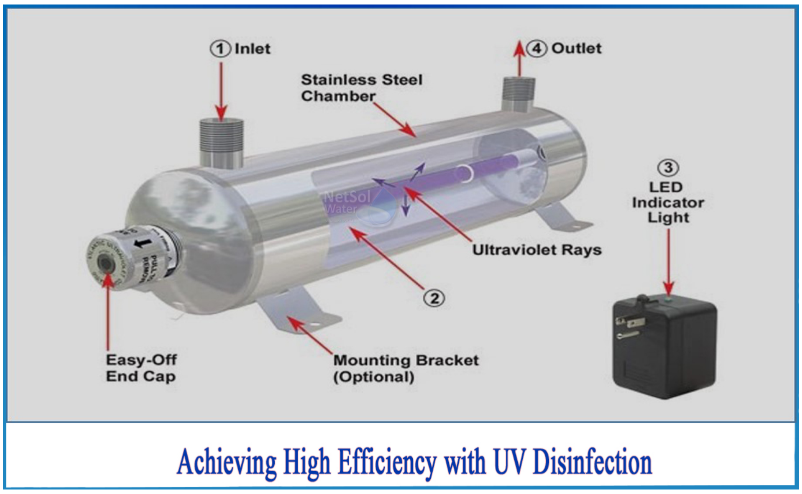

FIGURE 3.13: UV disinfection unit

Design & Balance :

$$\begin{aligned}
\text{Incoming mass flow rate to unit} &= 271536\,\mathrm{kg/day} \Rightarrow 271.536\,\mathrm{m^3/day} \\
\text{Density of the liquid flowing inside the unit} &= 1000\,\mathrm{kg/m^3} \\
\text{Volumetric flow rate of the incoming liquid} &= 271.536\,\mathrm{m^3/day} \\
\text{Retention time in the unit} &= 15\,\text{seconds} = 4.1 \times 10^{-3}\,\text{hours} \\
\text{(Typically between 5 to 30 seconds)} & \\
\text{Volume} &= \text{Volumetric flow rate} \times \text{Detention time} \\
&= 271.536 \times 4.1 \times 10^{-3}/24 = 4.6 \times 10^{-2}\,\mathrm{m^3} \\
\text{Energy Required} &: 100 - 250\,\mathrm{kWh/MG} \\
\text{Let's take} &: 200\,\mathrm{kWh/MG} \\
1\,\text{million gallons} &= 3,785,411.78\,\text{cubic meters} \\
\text{Volume of UV Disinfection Unit} &: 4.6 \times 10^{-2}\,\mathrm{m^3} \\
\text{Energy Required} &: 0.014\,\mathrm{kWh/day}
\end{aligned}$$

3.5.5.2 Chlorination

Chlorination in wastewater treatment involves the addition of chlorine or chlorine compounds to disinfect or treat wastewater. The process helps to kill or deactivate harmful microorganisms, such as bacteria and viruses, present in the wastewater.

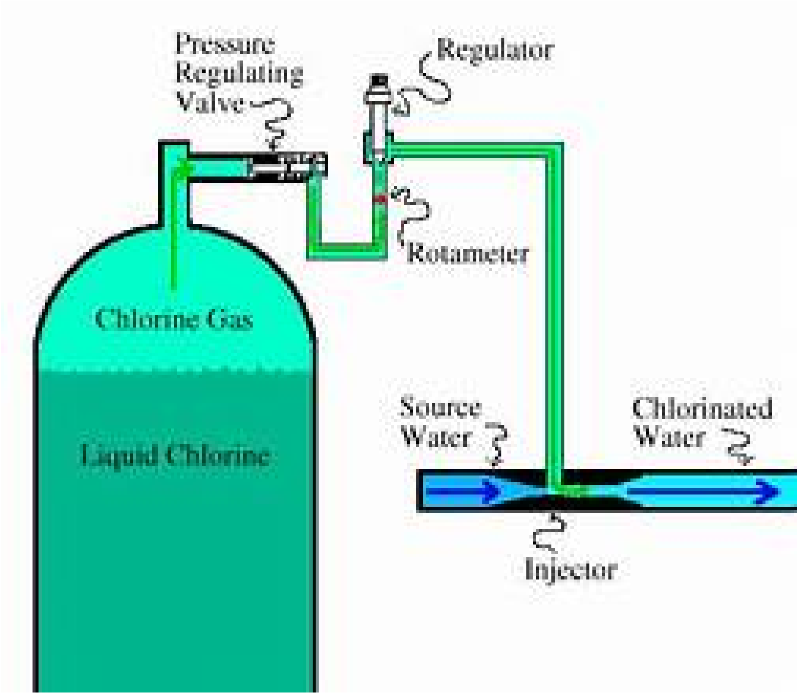

FIGURE 3.14: Chlorination equipment

Equipment Design:

$$\text{Incoming mass flow rate to Chlorination unit} = 271536\,\text{kg/day}$$

$$\text{Density of the liquid flowing inside the Chlorination unit} = 1000\,\text{kg/m}^3$$

$$\text{Volumetric flow rate of the incoming liquid} = \frac{271536}{1000}$$

$$= 271.536\,\text{m}^3/\text{day}$$

$$\text{Retention time} = 1\,\text{hour}$$

(Typically should be less than 2 hours)

$$\text{Volume of the Chlorination unit} = \text{Volumetric flow rate} \times \text{Retention tim}$$

$$= 271.536 \times 1/24$$

$$= 11.314\,\text{m}^3$$

$$\text{Volume of the Chlorination unit} = 11.314\,\text{m}^3$$

3.5.6.1 Gravity Thickener

"Gravity thickening" in wastewater treatment refers to a process where sludge (a semi-solid material consisting of water and solid particles) settles and accumulates at the bottom of a tank due to gravity. This process is employed to separate solids from liquid in sewage sludge, making it easier and more cost-effective to handle and dispose of the waste.

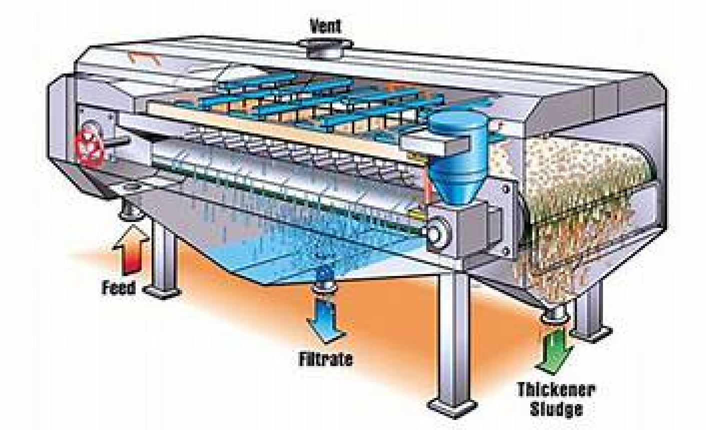

FIGURE 3.15: Gravity thickener

3.5.6 Sludge Treatment Equipments

Design & Balance:

SLUDGE TREATMENT PROCESS (BIOGAS PRODUCTION):

$$\begin{aligned}\text{Total BOD removed from clarifier} &= 25384.44\,\text{g/day}\\ \text{Biogas yield coefficient} &= 0.35\,\text{L/g BOD removed}\\ \text{Total Biogas Production} &= 0.35 \times 25384.44\\ &= 8884.56\,\text{L/day (Biogas produced)}\end{aligned}$$

GRAVITY THICKENER:

Assuming the current average solids concentration entering the gravity thickener is 75%, we calculate the initial solids flow rate as follows:

$$\begin{aligned}
\text{Total Dry Weight} &= \text{Mass Flow Rate} \times \text{Solids content} \\
&= (15.33\,\text{Kg/Day}) \times 0.75 \\
&= 11.4975\,\text{Kg/Day} \\
\text{Solids Flow Rate} &= \text{Total Dry Weight} \times \text{Solids concentration} \\
&= 11.4975\,\text{Kg/Day} \times 0.75 \\
&= 8.623\,\text{Kg/Day}
\end{aligned}$$

The solids concentration increases to 95%:

$$\begin{aligned}
\text{Concentrated Solids Flow Rate} &= \text{Initial Solids Flow Rate} \times \frac{\text{Increase in Concentration}}{1 - \text{Increase in Concentration}} \\
&= 8.623 \times \frac{0.95 - 0.75}{1 - 0.2} \\
&= 2.155\,\text{Kg/Day} \\
\text{New Total Solids Flow Rate} &= \frac{\text{Concentrated Solids Flow Rate}}{\text{Concentration Factor}} \\
&= \frac{2.155}{0.78} \\
&= 2.763\,\text{Kg/Day}
\end{aligned}$$

This means that the gravity thickener has successfully increased the solids concentration by a factor of $\frac{8.623}{2.763} = \mathbf{3.12}$

3.5.7 Sludge Treatment Equipments

3.5.7.1 Anaerobic digsester

An anaerobic digester in wastewater treatment is a specialized system designed to break down organic matter in wastewater without the presence of oxygen. It's a biological process where microorganisms decompose organic materials, such as sewage sludge or industrial waste, producing biogas (a mixture of methane and carbon dioxide) and a nutrient-rich effluent.

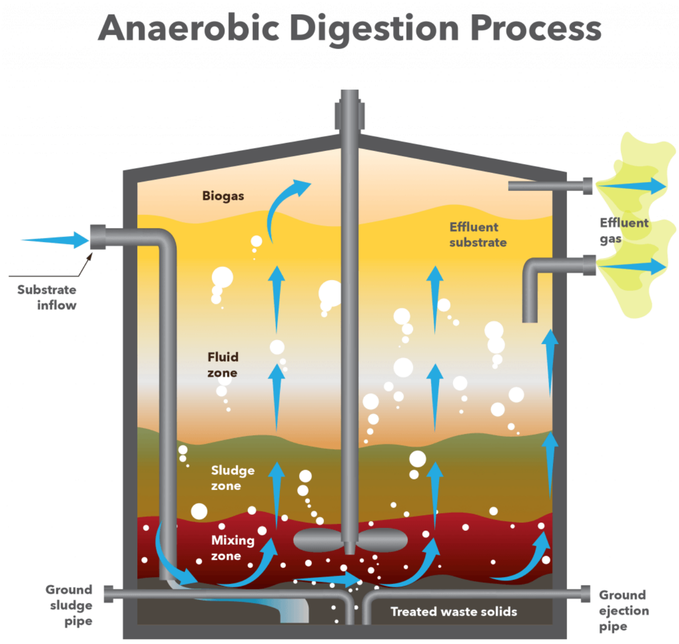

FIGURE 3.16: Anaerobic Digester

Gravity Thickener: Increases the TS concentration from 2% to 6%. This reduces the volume of sludge requiring further treatment, saving energy downstream.

Anaerobic Digestion (Biogas Production): Let's assume a conservative estimate of 0.5 m^3 biogas per kg TS fed to the digester. Here, with 60% methane in

Biogas:

$$\begin{aligned}
\text{Lower Heating Value (LHV) of biogas} &\approx (0.6 \times \text{LHV of methane}) + (0.4 \times \text{LHV of } CO_2) \\
&= (0.6 \times 50\,\mathrm{MJ/m}) + (0.4 \times 10\,\mathrm{MJ/m}) \\
&= 32\,\mathrm{MJ/m}
\end{aligned}$$

Biogas Energy Output: Biogas production rate (0.5 $\mathbf{m^3}$/kg TS) $\times$LHV of biogas (32 MJ/m)

$= 16\,\mathrm{MJ/kg}$

Total energy $= 16\,\mathrm{MJ/kg} \times 8.8845 \times 1000 \times 0.278/1.158$

$= 34126.3\,\mathrm{Wh/day}$

$= 341.26\,\mathrm{kWh}\ /\ \mathrm{day}$

$$\begin{aligned}
\text{Mass flow rate of sludge in the digester} &= 1.804\,\mathrm{kg/day} \\
\text{Sludge density} &= 1400\,\mathrm{kg/m^3} \\
\text{Volumetric flow rate} &= \frac{1.804\,\mathrm{kg/day}}{1400\,\mathrm{kg/m^3}} \\
&= 0.00128857\,\mathrm{m^3/day} \\
\text{Detention time} &= 30\,\text{hours} \\
\text{Volume} &= 0.00128857 \times 30 \\
&= 0.03857\,\mathrm{m^3}
\end{aligned}$$

3.5.7.2 Dewatering press

The Dewatering press typically consists of a series of rollers or plates that apply pressure to the sludge, squeezing out the water and leaving behind more solid material. This solid material can then be disposed of more easily, while the separated water can undergo further treatment or be discharged safely.

FIGURE 3.17: Dewatering press

Mass flow rate of sludge entering the dewatering press = 1.8045 kg/day

$$\begin{aligned}
\text{Solids content in the entry} &= 95\% \\
\text{Solids content in the exit} &= 97\% \\
\text{Energy consumption for dewatering} &= 1.2\,\text{kWh/m}^3 \text{ (range: } 0.3 \text{ to } 2.1\,\text{kWh/m}^3\text{)} \\
\text{Water content in the entry} &= 100\% - 95\% = 5\% \\
\text{Water content in the exit} &= 100\% - 97\% = 3\% \\
\text{Change in water content} &= 5\% - 3\% = 2\% \\
\text{Mass of water removed} &= \text{Change in water content} \times \text{mass flow rate per day} \\
&= 2\% \times 2.763\,\text{kg/day} = 0.055\,\text{kg/day} \\
\text{Energy required for dewatering} &= \frac{\text{Energy consumption} \times \text{Mass of water removed}}{1400\,\text{kg/m}^3} \\
&= \frac{(1.2\,\text{kWh/m}^3 \times 0.055\,\text{kg/day})}{1400\,\text{kg/m}^3} \\
&= 0.00047\,\text{kWh/day} \\
\text{Average density of concentrated sludge} &= 1400\,\text{kg/m}^3
\end{aligned}$$

Mass flow rate of sludge entering = 1.8045 kg/day

3.5.7.3 Sludge cake pump

Sludge cake pump in wastewater treatment is a type of pump used to transfer or move sludge cake, which is the solid residue left after the treatment of wastewater. This pump is specifically designed to handle the thick, viscous consistency of sludge cake, which can be challenging to transport due to its high solids content.

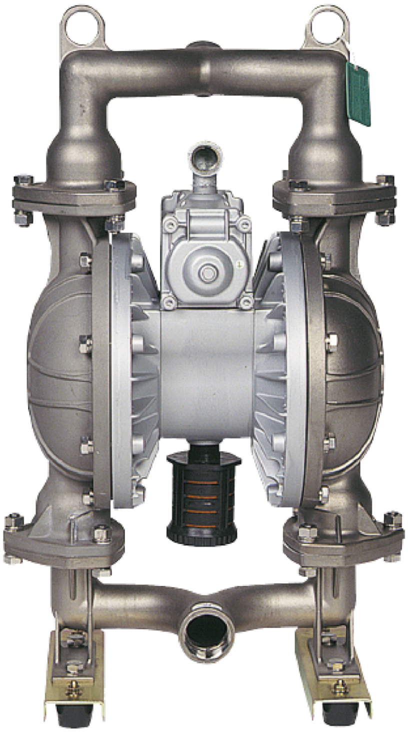

Figure 3.18: Sludge Cake Pump

$$\text{Sludge cake density} : 1500\,\text{kg/m}^3 \text{ (typical for dewatered sludge cakes)}$$

$$\text{Cake flow rate} : 10\,\text{m}^3/\text{hr}$$

$$\text{Pumping distance} : 50\,\text{meters}$$

$$\text{Pipe diameter} : 0.2\,\text{meters}$$

Energy Consumption Calculation:

$$
\begin{aligned}
\text{Mass flow rate}(\dot{m}) &= \text{Density}(\rho) \times \text{Volume flow rate}(Q) \\
\dot{m} &= 1500\,\text{kg/m}^3 \times 10\,\text{m}^3/\text{hr} = 10,000\,\text{kg/hr} \\
\text{Head pressure} &: \text{Assume a head pressure of 10 meters due to friction.} \\
&\text{(ignoring elevation for simplicity)} \\
\text{Pump power}(P) &= \frac{(\dot{m} \times g \times h)}{\eta} \\
&= \frac{(10,000\,\text{kg/hr} \times 9.81\,\text{m/s}^2 \times 10\,\text{m})}{0.6} \approx 1.64\,\text{kW/hour} \\
\text{Energy Requirement} &= 1.64\,\text{kW/hour} \times 24\,\text{hrs} = 39.36\,\text{kWh/day}
\end{aligned}
$$

3.5.8 Storage Plant

3.5.8.1 For Treated Water

- The tank is often constructed from materials resistant to corrosion and leakage to ensure the quality of the stored water.
- It may include mechanisms for monitoring water levels, maintaining water quality, and facilitating distribution to the intended end-users

3.5.8.2 For Biogas

- Common storage methods include gas holders, gasometers, or even underground storage tanks, depending on the volume of biogas generated and site-specific considerations.
- Biogas storage systems must be constructed with materials that are resistant to the corrosive nature of biogas and designed to withstand pressure fluctuations.

3.5.9 A general idea of Costing of Equipment

Cost of Equipment:

- UV Disinfection Unit: Rs. 1,00,000 [Reference]
- Coarse Mechanical Bar Screen (12.5m^3/hr flow rate): Rs. 2,00,000 (approximately $2,700 USD) [Reference]
- Grit Chamber: Rs. 3,00,000 [Reference]
- Primary Clarifier: Rs. 10,00,000 [Reference]
- Grease Trap: Rs. 16,200 [Reference]
- Effluent Treatment Filter Press: Rs. 20,000 [Reference]
- UV Disinfection Chamber: Rs. 1,77,000 [Reference]
- Rev-phc pH Correction Formulation for Anaerobic Digesters Powder Grade (5 kg): Rs. 42,000 [Reference]
- Self-cleaning Dewatering Screw Press: Rs. 1,00,000 [Reference]
- Diaphragm Pump: Rs. 1,00,000 [Reference]

- Sludge Drying Beds: Rs. 4,66,000 [Reference]
- Air Diffuser for Aeration Process: Rs. 1000 [Reference]

Total Capital Cost: Rs. 34,32,200

Energy Cost:

- Total Energy Required per Day: 1349.99 kWh
- Cost of 1 kWh in India: Rs. 7.05
- Total Cost for Energy per Day: Rs. 9518 (approx.)

Biogas Production:

- Biogas Production: 8.845 KLD = 10.17 m^3 per day
- Price of Biogas: Rs. 70
- Income from Biogas per Day: Rs. 712

Chapter 4

Results

4.1 Results pertaining to specifications of each process and equipment

This chapter provides an overview of the results of the equipment design, material balances and energy balances of various equipmets/processes involved in the waste water treatment plant.

4.1.1 Equipment Design Specifications

4.1.1.1 Bar Screening

Dimensions : 2 m x 0.075 m x 0.1129 m (LxBxH)

No. of bars = 3

4.1.1.2 Grit Chamber

Total length = 18.75 m

Total depth = 0.316 m

Dimensions: 18.75m x 0.116m x 0.316m(LxBxH)

4.1.1.3 Equalisation tank

Volume = 4 m x 3.5 m x 2.6 m (LxBxH)

4.1.1.4 Primary Fermenter/Clarifier

Volume of the tank = 18.12 m^3

Length of the tank = 6 m

Diamter of the tank = 3m

4.1.1.5 Aeration Tank

Volume = Flow rate $\times$ Aeration time = 293.76 m^3

Dimensions : 10 m x 4 m x 7.315 m (LxBxH) L/D = 10/4 =2.5

4.1.1.6 Secondary Clarifier

Volume = 543.075 m^3 (assuming 2.5 hrs as detention time)

L = 14.03 m

D = 7.01 m

L/D = 2

Dimensions : 14.03 x 7.01 (LxD)

4.1.1.7 Effluent Filter

Volume of Effluent Filter = 9.504 m^3

4.1.1.8 Chlorination Unit

Volume of the Chlorination unit = 11.314 m^3

4.1.1.9 UV Disinfection Unit

Volume of UV Disinfection Unit = 4.6 x 10^{-2} m^3

4.1.1.10 Anaerobic digester

Volume = 0.00161 m^3

4.1.2 Material balance calculations

4.1.2.1 Bar Screening

Solids in : Q_{in} x Influent TSS = 22200 g/day

Solids out : Q_{out} x Effluent TSS = 12287.5 g/day

Solids removed : 9912.5 g/day

Q : KLD

TSS : mg/L

4.1.2.2 Grit Chamber

Influent Grit Load = 105.84 kg/day

Effluent Grit Load = 10.584 kg/day

Grit Removed by Settling = 95.256 kg/day

4.1.2.3 Primary Fermenter/Clarifier

BOD% removal = 25 %

TSS % removal = 55 %

Treated Water mass Rate = 271550 kg/day

Water left = 271543.22 kg/day

4.1.2.4 Aeration Tank

Required Oxygen Flow Rate = 5.475 kg/hour

Required Air Flow Rate = 26.07 kg air/hour

4.1.2.5 Secondary Clarifier

Remaining TSS = 283.79 g/day

Water remaining = 271537.22 kg/day

4.1.2.6 Effluent Filter

TSS Removed = 0.255 kg/day

Water Out = 271536 kg/day

4.1.2.7 Chlorination Unit

Required Chlorine = 0.814 kg/day

4.1.2.8 Biogas production

Total Biogas Production = 8884.56 L/day

4.1.2.9 Gravity Thickener

Total Solids Flow Rate = 2.763 kg/day

This means that the gravity thickener has successfully increased the solids concentration by a factor of $8.623 \div 2.763 = 3.12$

4.1.2.10 Dewatering press

Mass of water removed = 0.055 kg/day

Solid Concentration increases by 2 %

4.1.3 Energy balance analysis

4.1.3.1 Bar Screening

Velocity head of approaching rack (h_v) = 0.0081 m

Head loss = 0.0353 m

Energy Required =3 Hp or 2.24 kWh/day

4.1.3.2 Grit Chamber

Energy used = 127 kWh/day

4.1.3.3 Primary Fermenter/Clarifier

E_{Mixing} = 10 kWh/batch

E_{pumps} = 6 kWh/batch

Total Energy Required = 264 kWh/day

4.1.3.4 Secondary Clarifier

E_{Motor} = 120 kWh/day

$E_{recirculation}$ = 240 kWh/day

Total Energy required = 360 kWh/day

4.1.3.5 Effluent Filter

Total Energy Required = 5.5 kWh/day

4.1.3.6 Chlorination Unit

Energy required = 27.1536 kWh/day

4.1.3.7 UV Disinfection Unit

Energy Required = 0.014 kWh/day

4.1.3.8 Anaerobic digester

Energy Requirement: 341.26 kWh/day

4.2 Conclusion

Our waste water treatment project presents a new way to solve environmental problems while getting useful things from it. With its ability to process 375,000kg of wastewater per day, the system has the following features:

Production of clean drinking water: We are able to produce around 271,563 kg of purified drinking water every day by using advanced techniques of purification. This treated water is safe for human consumption because it meets all required standards for quality.

Biogas production: Our procedure does not only purify water but also generates biogas at a rate of 8.8845 kiloliters per day (KLD). This biogas mostly contains methane gas which can be used as fuel for heating or producing electricity thus making it renewable energy resource hence contributing towards sustainable energy practices.

Efficiency in Energy Utilization: Despite the amount produced, our scheme consumes less power than expected. The daily energy consumption of our facility is estimated at 39.36 kWh which is quite low considering its huge outputs in terms of quantity and quality; this implies that cost-effective measures were taken into account during design stage so as not to adversely affect environment while still saving on costs.

Chapter 5

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