O&M MANUAL OF WASTE WATER TREATEMENT PLANTS

ENERGY MANAGEMENT AND OPERATION & MAINTENANCE OF 16 SELECTED MCS SERVICES INFRASTRUCTURE ASSETS PROJECT

AUGUST 18, 2023

PITCO (PRIVATE) LIMITED

Contents

List of Figures

List of Tables

Abbreviations

Acronyms	Definition
BOD	Biological Oxygen Demand
CAS	Conventional Activated Sludge
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
HRT	Hydraulic Retention Time
MBR	Membrane Bioreactors
MBBR	Moving Bed Biofilm Reactors
MC	Municipal Committee
O&M	Operation and Maintenance
SBR	Sequencing Batch Reactors
TDS	Total Dissolved Oxygen
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
WSP	Waste Stabilization Pond
WWTP	Waste Water Treatment Plant

1. INTRODUCTION TO WASTE WATER TREATMENT PLANT

1.1. Overview of Wastewater Treatment

Wastewater is essentially the water supply of the community after it has been used in a variety of applications and which now contains constituents that render it unsuitable for most uses without treatment. When untreated wastewater accumulates and is allowed to go septic. the decomposition of the organic mailer it contains will lead to nuisance conditions including the production of malodorous gases. In addition, untreated wastewater contains numerouss pathogenic micro-organizams that dwell in the human intestinal tract. Wastewater also contains nutrients, which can stimulate the growth of aquatic plants, and may contain toxic compounds or compounds that potentially may be mutagenicc or carcinogenic. For these reasons, the immediate and nuisance-free removal of wastewater from its sources of generation, followed by treatment, reuse, or disposal into the environment, is necessary to protect public health and the environmentt.

The most appropriate wastewater treatment to be applied before effluent use in agriculture is that which will produce an effluent meeting the recommended microbiological and chemical quality guidelines both at low cost and with minimal operational and maintenance requirements. Adopting as low a level of treatment as possible is especially desirable in Pakistan, not only from the point of view of cost but also in acknowledgement of the difficulty of operating complex systems reliably. In many locations it will be better to design the reuse system to accept a low-grade of effluent rather than to rely on advanced treatment processes producing a reclaimed effluent which continuously meets a stringent quality standard.

The design of wastewater treatment plants is usually based on the need to reduce organic and suspended solids loads to limit pollution of the environment. Pathogen removal has very rarely been considered an objective but, for reuse of effluents in agriculture, this must now be of primary concern and processes should be selected and designed accordingly.

Conventional wastewater treatment consists of a combination of physical, chemical and biological processes and operations to remove solids, organic matter and sometimes nutrients from wastewater. Wastewater treatment methods can be broadly classified as:

(i) Physical unit operation: The removal of pollutants by physical forces.

(ii) Chemical unit operation: The removal of pollutants by addition of chemicals or by chemical reactions.

(iii) Biological unit operation: The removal of pollutants by biological activities. These treatment methods occur in a variety of combinations in wastewater treatment systems, to provide various levels of wastewater treatment.

There are generally four levels of wastewater treatment:

1) Preliminary treatment
2) Primary treatment
3) Secondary treatment
4) Tertiary/advanced treatment.

1.1.1. Preliminary Treatment

The objective of preliminary treatment is the removal of coarse solids and other large materials often found in raw wastewater. Removal of these materials is necessary to enhance the operation and maintenance of subsequent treatment units. Preliminary treatment operations typically include coarse screening, grit removal and, in some cases, commination of large objects. In grit chambers, the velocity of the water through the chamber is maintained sufficiently high, or air is used, so as to prevent the settling of most organic solids. Grit removal is not included as a preliminary treatment step in most small wastewater treatment plants.


Figure 1-1: Screening

Comminutes are sometimes adopted to supplement coarse screening and serve to reduce the size of large particles so that they will be removed in the form of a sludge in subsequent treatment processes. Flow measurement devices, often standing-wave flumes, are always included at the preliminary treatment stage.

1.1.2. Primary Treatment

The objective of primary treatment is the removal of settleable organic and inorganic solids by sedimentation, and the removal of materials that will float (scum) by skimming. Approximately 25 to 50% of the incoming biochemical oxygen demand (BOD_5), 50 to 70% of the total suspended solids (SS), and 65% of the oil and grease are removed during primary treatment. Some organic nitrogen, organic phosphorus, and heavy metals associated with solids are also removed during primary sedimentation but colloidal and dissolved constituents are not affected. The effluent from primary sedimentation units is referred to as primary effluent.

Figure 1-2: Primary Treatment

1.1.3. Secondary Treatment (Biological)

The objective of secondary treatment is the further treatment of the effluent from primary treatment to remove the residual organics and suspended solids. In most cases, secondary treatment follows primary treatment and involves the removal of biodegradable dissolved and colloidal organic matter using aerobic biological treatment processes. The settlement of solids takes place in secondary sedimentation tank.

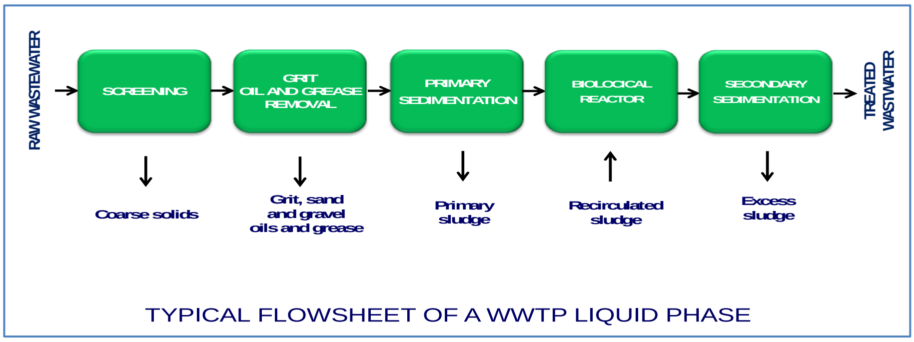


Figure 1-3: Typical flow sheet of a WWTP

Figure 1-4: Secondary Treatment (Biological Reactor)

Figure 1-5: Secondary Sedimentation Tank

1.1.4. Advanced or Tertiary Treatment

- Tertiary treatment is the final cleaning process that improves wastewater quality before it is reused, recycled or discharged to the environment.
- The treatment removes remaining inorganic compounds, and substances, such as the nitrogen and phosphorus.
- Bacteria, viruses and parasites, which are harmful to public health, are also removed at this stage.
- Tertiary treatment can remove more than 99 percent of all the impurities from sewage, producing an effluent of almost drinking-water quality.

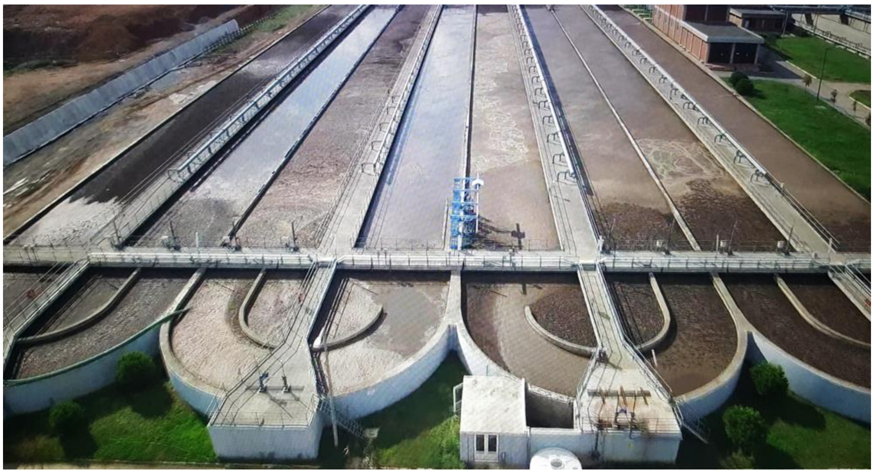


Figure 1-6: Tertiary Treatment Continuous nitrification/De-nitrification

1.2. Importance of Operation and Maintenance (O&M)

The successful operation and maintenance (O&M) of a wastewater treatment plant (WWTP) are pivotal to its performance and longevity. Wastewater treatment plants are not just structure with equipment for chosen technology in the aim to meet the standards, eliminate odour, flies, etc. Wastewater treatment facilities are more complex, raw water is more difficult to treat and there is an increasing expectation in service, operation and control in exploitation. Therefore, the costs for normal operation of a WWTP are usually rather high. Thus, the very important roles in WWTP working life are an economic operation, control and maintenance, all together in the purpose for reliable operation of WWTP to meet regulatory requirements.

Operations are the activities to make sure the plant produces the desired quality and quantity of treated water and meets the current legislation. Wastewater collection and treatment system must be operated as designed to adequately meet standard of the effluent and protect water quality. Operators of the WTTPs manage a complex system of machines, often using control boards, to transfer or treat wastewater.

Maintenance are the activities that should be undertaken to ensure the plant equipment operates continuously and efficiently to achieve operational objectives. Wastewater treatment plant must provide reliable and stabile service and avoid equipment breakdowns. Breakdowns of the equipment usually can be avoided if operators regularly inspect the equipment, pipelines, inlet and outlet of the system. Based on the proper instruction and educated staff, good maintenance program will reduce breakdowns and contribute to the cost-effective operation of the WWTP.

Following are some key points focusing on the various facets of the importance of Operation and Maintenance (O&M) of WWTPs

1.2.1. Regulatory Compliance

O&M ensures that WWTPs meet legal standards by monitoring critical parameters like pH, BOD, and nutrients. Compliance with these regulations safeguards public health and prevents environmental damage. Failing to adhere to these standards may result in legal ramifications and a loss of public trust.

1.2.2. Performance Optimization

Proper O&M is vital for the optimal functioning of a WWTP. Regular maintenance, coupled with accurate monitoring, allows the plant to adapt to changes in influent quality and quantity. This responsiveness ensures the efficiency of the treatment process, conserving energy, and reducing operational costs.

1.2.3. Public Health Protection

O&M practices are crucial for maintaining public health standards. Effective disinfection processes eliminate harmful pathogens, and regular maintenance controls unpleasant odors. The failure of these processes can lead to health risks for the community and neighboring ecosystems.

1.2.4. Asset Management and Cost-Efficiency

Routine maintenance extends the lifespan of critical equipment, such as pumps and aerators, preserving the plant's assets. By implementing preventive maintenance schedules, unexpected breakdowns and costly emergency repairs can be minimized, contributing to overall cost efficiency.

1.2.5. Resource Recovery

Efficient O&M facilitates water recycling and resource recovery, such as energy from biogas and nutrients for agriculture. These practices contribute to sustainability by turning waste into valuable resources, but they require meticulous operation and maintenance to function effectively.

1.2.6. Environmental Stewardship

Ensuring proper treatment and disposal through rigorous O&M protects aquatic ecosystems and mitigates climate impact. The well-managed operation prevents harmful discharges that can have long-lasting detrimental effects on the environment, highlighting the plant's role in ecological preservation.

Figure 1-7: O&M of WWTP

Figure 1-8: Maintenance of WWTP

2. REVIEW OF TREATMENT TECHNOLOGIES APPLIED AROUND THE WORLD

2.1. Aerated Lagoons System

It is similar to a facultative pond but mechanical aerators are used. Aerated lagoons are common in small communities. These systems use aerators to mix the contents of the pond and add oxygen to the wastewater. They are sometimes referred to as partial-mix or complete-mix lagoons depending on the extent of aeration. Partial-mix aerated lagoons are often anaerobic lagoons that have been adapted and upgraded to receive more wastewater. With the exception of wind-driven designs, most aerators require energy to operate. However, energy costs are almost always considerably less than those for other mechanical treatment systems. Aeration makes treatment more efficient, which offsets energy costs in some cases. Aerated lagoons require less land area and shorter detention times.

- Detention time is 5-10 days
- Usually, it is 2.5-4 meters deep
- The aerators more frequently used for aerated lagoons are the mechanical vertical- shaft high-speed floating aerators.
- Requires frequent desludging

Figure 2-1: Aerated Lagoons

2.1.1. Advantages & Disadvantages of AL

Advantages

- Lower land requirements than WSP
- Satisfactory resistance to load variations
- Reduced possibilities of bad odours

Disadvantages:

- Land requirements still high
- Relatively high energy requirements
- Low coliform removal efficiency
- Need for periodic (some years interval) removal of sludge from

2.2. Trickling Filters System

- This is an attached growth process. The influent wastewater is distributed/sprinkled over the rock or plastic filter and then trickles down the packing material,
- microorganisms already in the water gradually attach themselves to the media surface and form a biofilm (approximately 0.1 to 0.2 mm thick).
- The sewage is oxidized by the bacteria producing effluent in the form of water, gases and new cells.

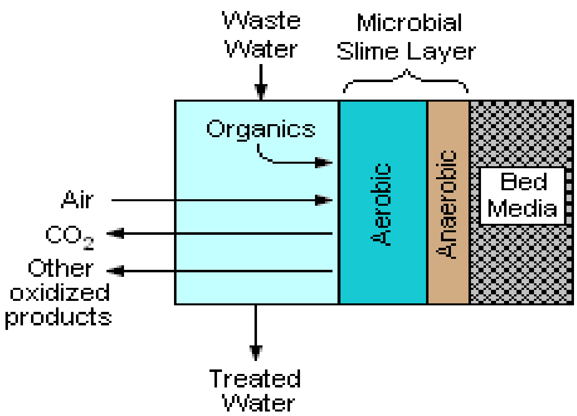


Figure 2-2: Slime Layer Over Media

- The influent wastewater is distributed/sprinkled over the rock or plastic filter and then trickles down the packing material, microorganisms already in the water gradually attach themselves to the media surface and form a biofilm (approximately 0.1 to 0.2 mm thick).
- The sewage is oxidized by the bacteria producing effluent in the form of water, gases and new cells.

❖ The aerobic microorganisms in the outer part of the slime layer then degrade organic material.

❖ As the layer thickens through microbial growth, oxygen cannot penetrate the medium face, and anaerobic organisms develop.

❖ As the biological film continues to grow, the microorganisms near the surface lose their ability to cling to the medium, and a portion of the slime layer falls off the filter. This process is known as sloughing.

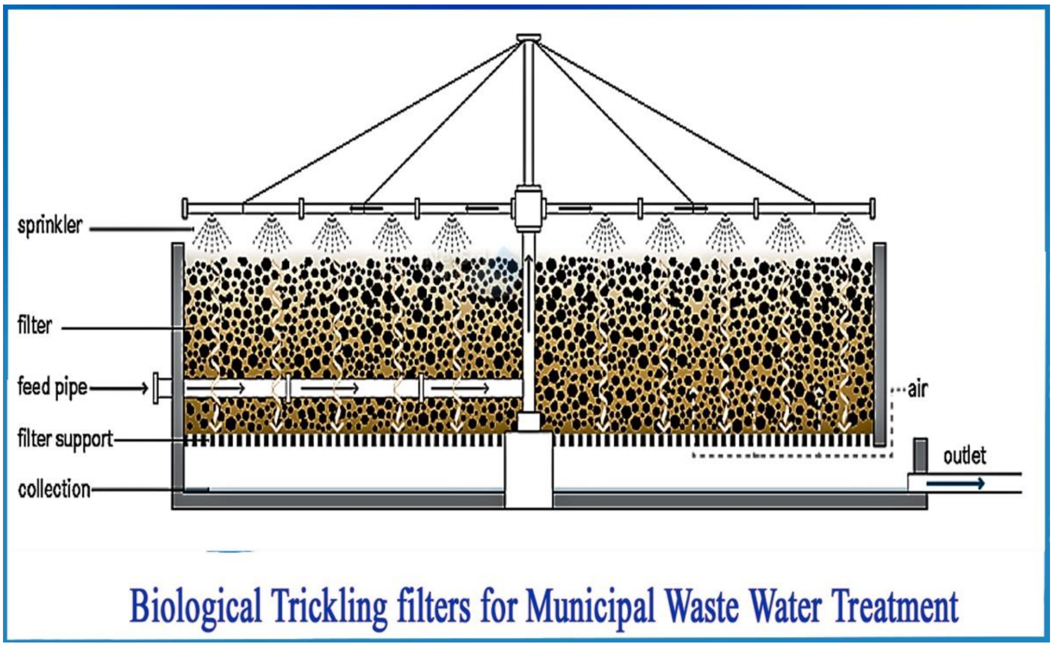


Figure 2-3: Trickling Filter sectional View

- The filter media (75 to 100 mm rock material or plastic packing),
- wastewater distribution system and,
- the undertrain system, which collects the wastewater that has passed through the filter and provide an open area for the movement of air.

Figure 2-4: Plastic Media

Figure 2-5: Sprinkler of a TF

Hydraulically driven rotary distributors use pneumatically-controlled gates that either open or close distributor orifices that adjust with varying pumped flows to maintain a constant preset rotational speed (left). On the right is an electrically driven rotary distributor

Trickling filters may be categorized as; Primarily based on hydraulic and organic loading rates.

- low rate,
- High rate, and
- super rate

Table 2-1: Advantages/Disadvantages of TF

Advantages	Disadvantages
Simple & easy to operate as compared to activated sludge	Difficulty in accomplishing biological nitrogen & phosphorus removal
Less energy required due to natural ventilation	Flies, worms and snails& odor can be nuisance
Appropriate for small- to medium-sized communities.	Additional treatment may be needed to meet more stringent discharge standards.
Less O&M	Clogging if overloaded
Possible energy production from sludge digestion	Not as efficient as CAS

2.3. Conventional Activated Sludge

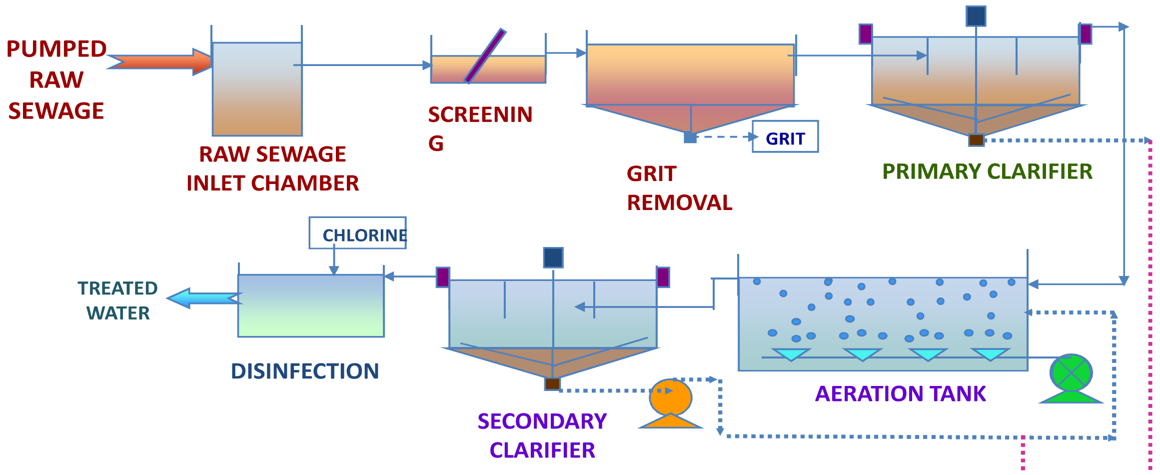


Figure 2-6: Flow Diagram of an Activated Sludge Process

The activated sludge process is widely used around the world for the treatment of domestic and industrial wastewater. It is used in situations where high effluent quality is necessary and space availability is limited. However, the activated sludge system is more heavily mechanized than the other treatment systems, involving a more sophisticated operation.

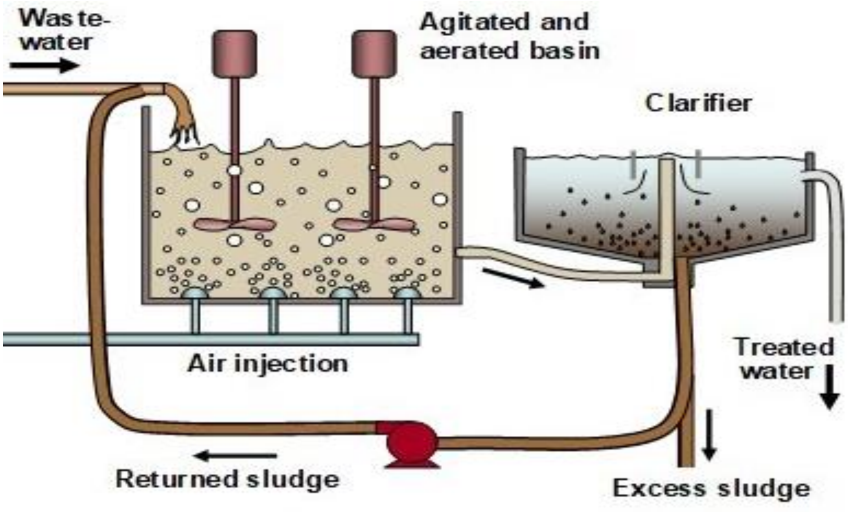


Figure 2-7: Return flow AS

After pre and primary treatment, the conventional activated sludge (CAS) process comprises:

- **Aeration tank,** in which the biomass responsible for organic matter aerated by a blower and diffuser system (or surface aeration system);
- **Secondary clarifier,** where the activated sludge settles;
- **Return Activated Sludge (RAS)** pumping station re-circulates most of the activated sludge from the secondary tank to the aerobic reactor to maintain the desired concentration of organisms.
- Daily a small part of the biomass is removed in order to keep the biomass in the system at a constant level.
- A complete treatment system is needed for primary sludge and WAS which can be used to produce biogas for energy recovery through Combined Heat and Power Plant (CHP).

Figure 2-8: Aeration Tank/Biological Reactor

Activated sludge process: Important components

- **SRT/MCRT(Mean Cell Residence Time):** Fundamental parameter. The average time suspended solids remain in the activated sludge system. Typical sludge age are: θc = 4 to 10 days

- **Food to microorganism's ratio(F/M)**
- F/M is a measurement of the food entering the activated sludge process and the microorganisms (bacteria) in the aeration tanks.
- **Hydraulic retention time (HRT).** Typical 6-14 hours

2.3.1. Advantages and Disadvantages

Table 2-2: Advantages/Disadvantages of AS

ADVANTAGES	DISADVANTAGES
Low land requirements	High construction costs
High operational flexibility: changes in the system can be achieved with a number of parameters (e.g. aeration flow rates, RAS flow rate, WAS.	High energy consumption, due to aeration requirements
The effluent quality is superior, high standard of BOD5 and ammonia removal are achieved	High operation costs
The process is reliable if the maintenance programme is followed	Requires operation and maintenance by skilled operators
Low possibility of odors, insects and worms	The process is susceptible to sludge bulking (the sludge fails to separate out in the sedimentation tank) due to filamentous bacteria;
Possible energy production from the digestion of sludge.	Need for complete sludge treatment and disposal

2.4. Sequencing Batch Reactors (SBR)

Sequencing Batch Reactors (SBR) are a special form of activated sludge treatment in which all of the treatment process takes place in the reactor tank and clarifiers are not required. This process treats the wastewater in batch mode and each batch is sequenced through a series of treatment stages.

It is suited for low or intermittent flow conditions. Flow is neither entering nor leaving the reactor i.e. flow enters, is treated, and then is discharged and the cycle repeats.

Figure 2-9: SBR Plant

Typical SBR Process

- Wastewater fills the tank, mixing with biomass that settles during the previous cycle
- Air is added to the tank to aid biologial growth and facilitate subsequent waste reduction.
- Mixing and aeration stop during this stage to allow solids to settle to the bottom of the tank
- Clarified effluent is discharged.
- If necessary, sludge removal occurs during this stage.

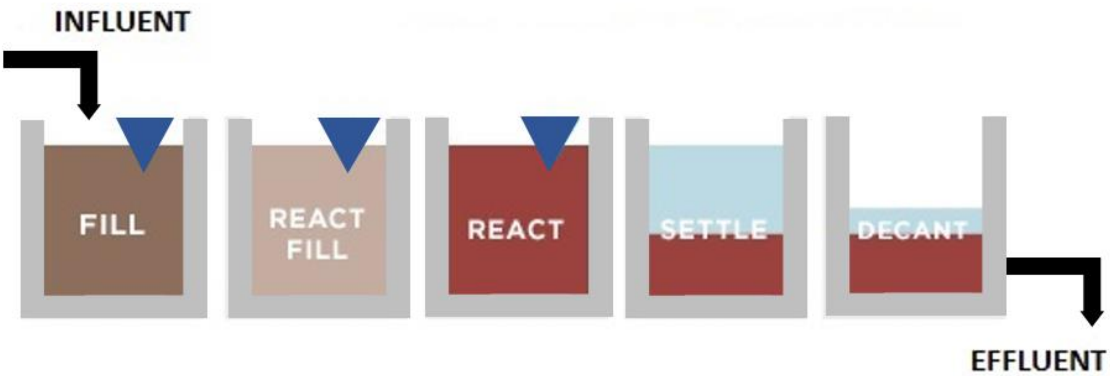


Figure 2-10: SBR sequence

Effluent Quality from well-designed SBRs

Table 2-3: Effluent quality of SBR

BOD	< 8.0 mg/L
TSS	< 8.0 mg/L
NH4-N	< 1.0 mg/L
NO3-N	<10.0 mg/L

2.5. Membrane Bioreactors (MBR)

Membrane Bioreactors (MBRs) represent a state-of-the-art wastewater treatment technology that combines conventional activated sludge treatment with membrane filtration. In an MBR system, the biological process occurs in an aeration tank where microorganisms break down organic matter, similar to the activated sludge process. What distinguishes MBR is the use of semipermeable membranes to perform the separation of the treated water from the mixed liquor.

- Membrane is integrated with a biological process. Vacuum-driven membranes may be immersed directly into the activated sludge reactor or in a separate membrane separation tank.
- To clean the exterior of the membranes, air is introduced below the membranes.
- While the CAS process uses a secondary clarifier for solid/liquid separation, an MBR uses a membrane for this function.

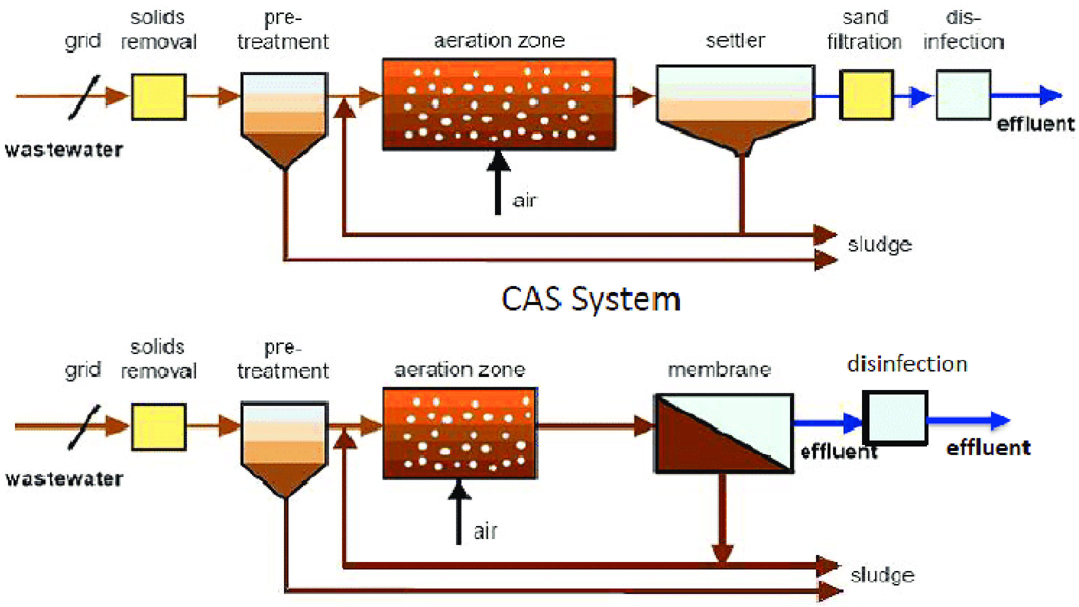


Figure 2-11: MBR and AS

- The idea behind this technology is to get extremely good quality effluent
- Mostly used for wastewater reuse purpose
- Aeration plus membrane energy consumption is 76 % in this process

Figure 2-12: MBR plant

Figure 2-13: Membranes inserted in to sewage

2.6. Moving Bed Biofilm Reactors (MBBR)

Moving Bed Biofilm Reactors (MBBR) are an advanced wastewater treatment technology that combines the benefits of both suspended growth and attached growth systems. The MBBR system utilizes thousands of small, floating plastic carriers, usually with a geometric design, that provide a large surface area for microorganisms to attach and grow. These carriers are kept in constant motion within the reactor by aeration or mechanical mixing, hence the term “moving bed.” The attached microorganisms form a biofilm on the carriers and function in a manner similar to that of the biological layer in a trickling filter, breaking down organic pollutants in the wastewater. The movement ensures that the biofilm is exposed to both wastewater and air, optimizing the treatment process.

Figure 2-14: MBBR media

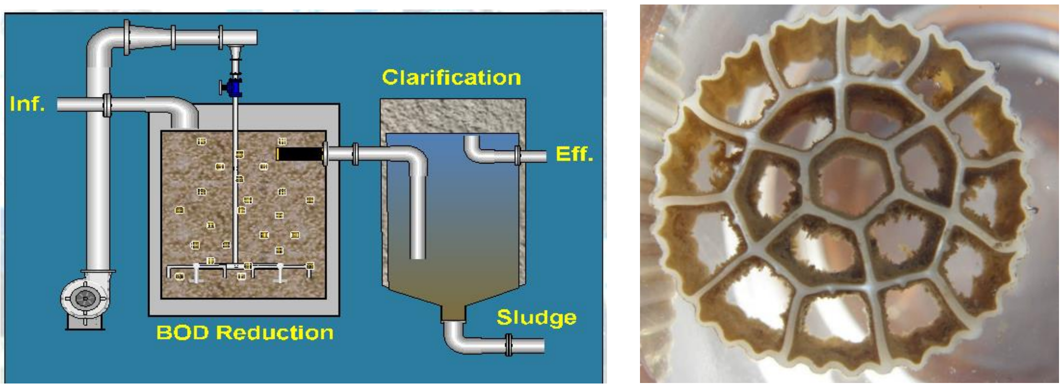


Figure 2-15: MBBR Process

- This system requires less space than CAS.
- The MBBR system consists of an activated sludge aeration system where the sludge is collected on recycled plastic carriers. These carriers have an internal large surface for optimal contact water, air and bacteria.
- More modern fixed film process in which the microorganisms grow on plastic media.
- The media are made from high density polyethylene or polypropylene with a diameter of 13 – 25mm, and therefore have a large surface area which helps the biomass to grow inside the surface and are in constant motion due to the compressed air that is blown from under the tank.

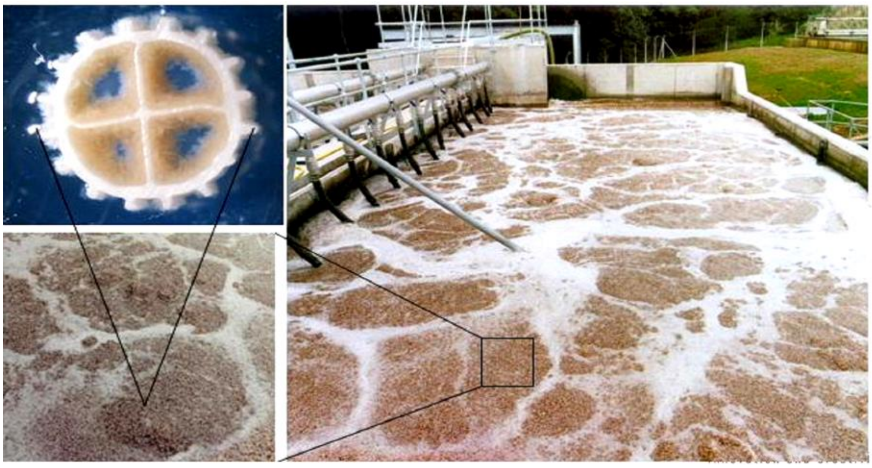


Figure 2-16: Aeration Tank with Attached Growth Media

2.6.1. Advantages

- Good for high organic loading applications
- Typical performance characteristics are – BOD in effluent <3 mg/L.
- Smaller foot prints. 1⁄4 the tank volume than AS.
- suitable for nitrification.
- A typical HRT for MBBR is 2 – 3 hours, compared to 12 – 24 HRT for ASPs.
- No need for sludge recirculation
- Self regulating biomass.

2.6.2. Disadvantages

- It requires a higher oxygen concentration as compared to ASP
- Need improved influent wastewater screening
- Energy consumption 0.17 – 0.27 kWh/m3 (for domestic sewage).

2.7. Extended Aeration Systems

Figure 2-17: Extended Aeration

Extended Aeration Systems are a specific type of activated sludge process used in wastewater treatment, characterized by a longer aerobic detention time. This extended time in the aeration tank allows for complete oxidation of organic matter and a higher degree of treatment. The system typically consists of an aeration basin where air is supplied to mix the wastewater with a microbial sludge, and a settling tank where the sludge is separated from the treated effluent. One significant advantage of Extended Aeration Systems is the reduced production of excess sludge, as more of the biomass is oxidized.

Extended aeration is typically used in prefabricated "packaged plants" intended to minimize design costs for waste treatment from small communities, tourism facilities and schools. Longer mixing time with aged sludge compared to conventional activated sludge results in a stable biological ecosystem suitable for effectively treating fluctuating waste loads due to occupancy fluctuations. Supplements such as sugar are sometimes used to maintain sludge microbial populations during periods of low occupancy.

It uses prolonged aeration. Prolonged aeration agitates all waste entering the sludge from a single clarifier. Combined sludge starts with a higher concentration of inert solids than typical secondary sludge, and the longer mixing time required to digest primary solids in addition to dissolved organics results in more waste per unit of waste oxidized. Aged sludge is produced which requires a large mixing energy input.

- The raw sewage goes straight to the aeration tank for treatment & no primary clarifier is required.
- The whole process is aerobic.
- This simplification implies longer aeration time.
- The BOD removal efficiency of the extended aeration process is higher than activated sludge process.

Advantages of Extended Aeration System

- Do not require a primary clarifier.
- Greater detention time for the nutrients to be assimilated by microbes.
- Systems are odor free
- Have a relatively small footprint.
- Have a relatively low sludge yield due to long sludge ages.

2.8. Oxidation ditches

- An oxidation ditch is a modified activated sludge biological treatment process that uses long solids retention times (SRTs) to remove biodegradable organics.
- Applicable in plants that require nitrification because the basins can be sized using an appropriate SRT to achieve nitrification at the mixed liquor minimum temperature.
- This technology is very effective in small installations, small communities, and isolated institutions, because it requires more land than conventional treatment plants.
- The wastewater moves through the ditch at 1 to 2ft/s.
- A carbon source (shown in the above equation as CH_3OH) is required for DE nitrification to occur. It may be wastewater with sufficient carbon source.

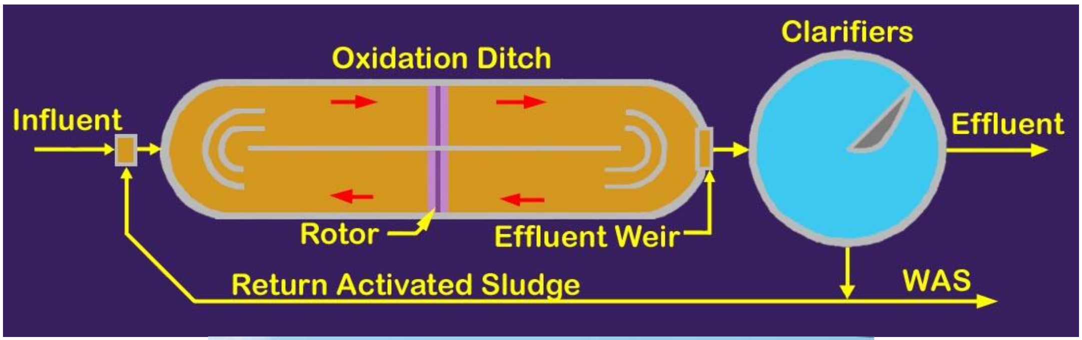


Figure 2-18: Oxidation Ditches

Table 2-4: Advantages/Disadvantages OD

Advantages	**Disadvantages**
High reliable process;	Requires more aeration energy than conventional CAS options;
The ditch (closed loop) configuration is the most energy efficient design available because it conserves fluid momentum.	Effluent suspended solids concentrations are relatively high compared to other modifications of the activated sludge process.
Use less energy than extended aeration;	Large sludge treatment facility is needed;
The BOD removal efficiency is better than the conventional method (up to 99%);	No primary tanks hence no biogas and energy production from the sludge.
High-quality effluent possible;	
Adaptable to nutrient removal;	

2.9. Anaerobic Digestion

The word *digestion* in wastewater treatment is applied to the stabilisation of the organic matter through the action of bacteria in contact with the sludge, in conditions that are favourable for their growth and reproduction. Digestion processes may be anaerobic, aerobic or even a combination of both. Table shows the main differences between raw sludge and digested sludge.

Table 2-5: Wastewater Treatment Processes and the Corresponding Degree of Sludge Stabilization

System	Characteristics of the sludge: Primary sludge	Secondary sludge	Chemical sludge
Primary treatment (conventional)	raw		
Primary treatment (septic tanks)	stabilised		
Primary treatment with coagulation (chemically enhanced)	raw		
Facultative pond		stabilised	
Anaerobic pond + facultative pond		stabilised	
Facultative aerated lagoon		stabilised	
Complete-mix aerated lagoon + sedimentation pond		stabilised	
Facultative pond + maturation pond		stabilised	
Facultative pond + high-rate pond		stabilised	
Facultative pond + physical-chemical algae removal		non-stabilised	
Slow rate infiltration		(a)	
Rapid infiltration		(a)	
Overland flow		(a)	
Wetland		(a)	
Septic tank + anaerobic filter	stabilised	stabilised	
Septic tank + infiltration	stabilised	(a)	
UASB reactor		stabilised	
UASB + activated sludge		stabilised (b)	
UASB + submerged aerated biofilter		stabilised (b)	
UASB + anaerobic filter		stabilised	
UASB + high-rate trickling filter		stabilised (b)	
UASB + flotation		stabilised	stabilised
UASB + polishing ponds		stabilised	
UASB + overland flow		stabilised (a)	
Conventional activated sludge	raw	non-stabilised	
Extended aeration		stabilised	
Sequencing batch reactor (extended aeration)		stabilised	
Conventional activated sludge with biological N/P removal	raw	non-stabilised	
Activated sludge with chemical and biological N/P removal		non-stabilised	non-stabilised
Low-rate trickling filter	non-stabilised	non-stabilised	
High-rate trickling filter	non-stabilised	non-stabilised	
Submerged aerated biofilter		non-stabilised	
Rotating biological contactor	non-stabilised	non-stabilised	

(a): In land-disposal wastewater treatment systems, the periodic removal of formed plant biomass is necessary
(b): Assumes return of the aerobic excess sludge to the anaerobic reactor, for further thickening and digestion, together with the anaerobic sludge

The anaerobic digestion process, characterized by the stabilization of organic matter in an oxygen-free environment, has been known by sanitary engineers since the late 19th century. Due to its robustness and efficiency, it is applied to small systems such as simple septic tanks (acting as an individual solution for a house) as well as in fully automated plants serving large metropolitan areas. The anaerobic digestion process underwent noticeable progresses between the First and the Second World Wars. Several concepts related to the process were improved at that time, especially in Germany, England and the United States, and are still being used today in the design of digesters.

Comparison between raw sludge and anaerobically digested sludge

Table 2-6: Comparison between raw sludge and anaerobically digested sludge

Raw sludge	Digested sludge
Unstable organic matter	Stabilised organic matter
High biodegradable fraction in organic matter	Low fraction of biodegradable organic matter
High potential for generation of odours	Low potential for generation of odours
High concentration of pathogens	Concentration of pathogens lower than in raw sludge

Anaerobic digestion is a multi-stage biochemical process, capable of stabilising different types of organic matter. The process occurs in three stages:

- Enzymes break down complex organic compounds, such as cellulose, proteins and lipids, into soluble compounds, such as fatty acids, alcohol, carbon dioxide and ammonia.
- Microorganisms convert the first-stage products into acetic and propionic acid, hydrogen, carbon dioxide, besides other low-molecular weight organic acids.
- Two groups of methane-forming organisms take action: one group produces methane from carbon dioxide and hydrogen, while a second group converts the acetates into methane and bicarbonates.

2.9.1. Process description

In a conventional activated sludge WWTP, mixed primary sludge and excess activated sludge are biologically stabilized under anaerobic conditions and converted into methane (CH_4) and carbon dioxide (CO_2). The process is accomplished in closed biological reactors known as anaerobic sludge digesters. Digester tanks are fed with sludge either continuously or in batches, and the sludge is kept inside the tank for a certain period of time previously determined during the design phase. The sludge and the solids have the same detention time in the digester.

The organic fraction of the sludge is basically made up of polysaccharides, proteins and fat. Inside the sludge digesters, colonies of anaerobic microorganisms convert the organic matter into cellular mass, methane, carbon dioxide and other micro-constituents. Inside the digester tank, three groups of mutually dependent Microorganisms coexist:

- hydrolytic acidogenic organisms
- acetogenic organisms
- methanogenic organisms

This population of microorganisms remains in a dynamic equilibrium and their concentrations vary depending upon the operational conditions within the tank. Sulphate-reducing and denitrifying bacteria are also microorganisms occurring in anaerobic digestion and playing a fundamental role in the stabilization process. The sulphate-reducing bacteria are responsible for the reduction of sulphate (SO^{2-}) to sulphide ($S^{=}$), while denitrifying bacteria reduce nitrate (NO^{-}) to 43 gaseous nitrogen (N_2).

2.9.2. Reduction of pathogens

Raw sludge concentrates a great variety of pathogenic organisms. The concentration and type of those organisms reflect the standard of living in the treatment plant service area. The presence and concentration of certain organisms in the raw sludge may also indicate the contribution from slaughterhouses or animal related centres. This is particularly true in small wastewater treatment plants serving rural areas.

Sludge digestion significantly reduces the population of organisms, favouring the agricultural use of the sludge. Anaerobic stabilization acts as a partial barrier between pathogenic agents and sludge users, reducing the risks of disease transmission.

Anaerobic digestion is achieved by obligatory anaerobic bacteria in the process of a **Upflow anaerobic sludge blanket.**
$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4$
Anaerobic digestion (AD) systems are designed to capture the biogas produced from this breakdown and produce energy.

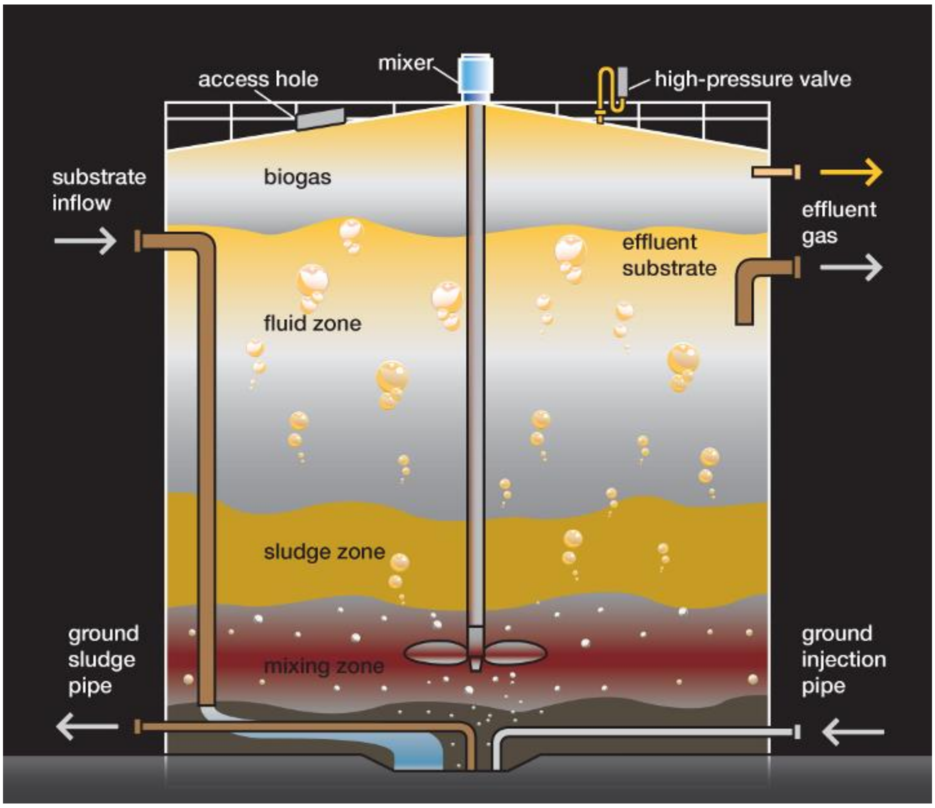


Figure 2-19: Upflow anaerobic sludge blanket

- UASB uses an anaerobic process whilst forming a blanket of granular sludge which suspends in the tank.
- The upward flow combined with the settling action of gravity suspends the blanket with the aid of flocculants.
- Organic components (COD) are converted to CH4 + CO2 + BIOMASS
- Gas liquid separator occupies remaining 15 to 30% of the total volume.
- A low energy requirement for the treatment process

- A proper temperature range is required for the anaerobic process (15 C to 35 C), therefore it is not applicable during cold season in certain countries.

3. TREATMENT SYSTEMS APPLIED IN MCs

3.1. Stabilization Pond Treatment System

Waste stabilization ponds (WSP) have been used world-wide over the last 50 years for municipal and domestic wastewater. Waste stabilization ponds (WSPs) are usually the most appropriate method of domestic and municipal wastewater treatment in developing countries, where the climate is most favorable for their operation. WSPs are low-cost, low-maintenance, highly efficient, entirely natural and highly sustainable. The only energy they use is direct solar energy, so they do not need any electromechanical equipment, saving expenditure on electricity and more skilled operation. They do require much more land than conventional electromechanical treatment processes such as activated sludge – but land is an asset which increases in value with time, whereas money spent on electricity for the operation of electromechanical systems is gone forever.

3.1.1. Description of the Process

Waste Stabilization Ponds (WSPs) are prominent natural methods for treating wastewater. These are either artificially constructed earthen or concrete basins that typically encompass a sequence of anaerobic, facultative, and, if higher effluent quality is desired, maturation ponds. WSPs are especially effective in tropical and subtropical regions due to the significant role of sunlight and warmth in their operational efficacy. Before being processed in the WSPs, wastewater undergoes initial treatments, including screening and grit elimination, to extract bulky and dense solids. While the design of this preliminary stage aligns with traditional electromechanical wastewater treatment systems, WSPs usually employ more straightforward, manual approaches like hand-raked screens and manually cleared constant-velocity grit channels.

Figure 3-1: WSP Plant

In essence, WSPs involve a three-tiered treatment approach: primary treatment before the anaerobic ponds, secondary treatment in the anaerobic and facultative ponds, and tertiary treatment within maturation ponds. The anaerobic and facultative ponds primarily address the reduction of organic matter, often referred to in terms of “biochemical oxygen demand” or BOD, as well as the elimination of Vibrio cholerae and helminth eggs. Conversely, maturation ponds focus on eradicating fecal viruses such as rotavirus, astrovirus, and norovirus, certain fecal bacteria like Salmonella spp., Shigella spp., Campylobacter spp., and specific strains of Escherichia coli, in addition to managing nutrient concentrations, specifically nitrogen and phosphorus.

3.1.2. Stages of waste stabilization ponds treatment

Stabilization ponds are broadly classified into three stages based on their function: anaerobic, facultative, and maturation or aerobic ponds, with each serving a different role in the treatment process.

Figure 3-2: Types of WSP

3.1.2.1. Anaerobic ponds

Anaerobic ponds constitute an alternative form of treatment, in which the existence of *strictly anaerobic* conditions is essential. This is reached through the application of a high BOD load per unit of volume of the pond, which causes the oxygen consumption rate to be several times greater than the oxygen production rate. In the oxygen balance, the production by photosynthesis and atmospheric reaeration are, in this case, negligible.

Anaerobic ponds have been used for the treatment of domestic sewage and organic industrial wastewaters, with high BOD concentrations, such as slaughter- houses, piggery wastes, dairies, beverage industries, etc.

The conversion of organic matter under anaerobic conditions is slow, owing to the slow growth rate of anaerobic bacteria. This results from the fact that the anaerobic reactions generate less energy than the aerobic reactions for the stabilisation of organic matter. The temperature of the medium has a great influence in the biomass reproduction and substrate conversion rates, which makes warm-climate regions to be favourable for the utilisation of this type of pond.

Anaerobic ponds are usually deep, of the order of 3 m to 5 m. The depth is important, in order to reduce the possibility of the penetration of the oxygen produced in the surface to the other layers. Because these ponds are deeper, the land requirements are correspondingly small.

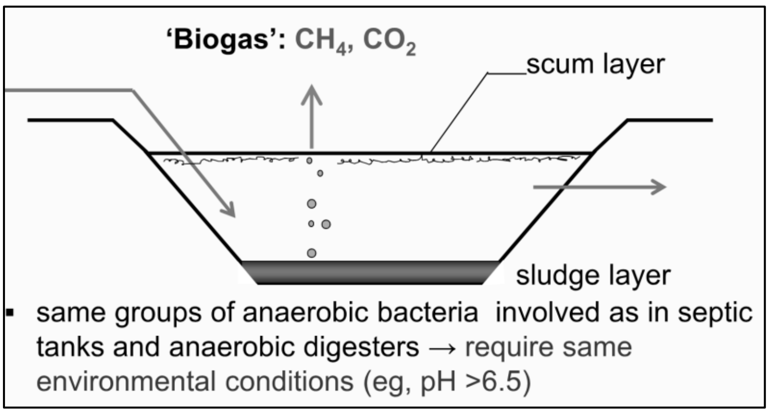


Figure 3-3: Anaerobic Pond

Anaerobic ponds do not require any special equipment and have a practically negligible energy consumption (for a possible pumping of the raw sewage or the recirculation of the final effluent).

The BOD removal efficiency in anaerobic ponds is usually of the order of 50% to 70%. The effluent BOD is still high and implies the need of a post-treatment unit. The most widely used post-treatment units are facultative ponds, composing the system of anaerobic ponds followed by facultative ponds.

The removal of BOD in the anaerobic pond provides a substantial saving in the area required for the facultative pond, making the total land requirement (anaerobic + facultative ponds) to be around 45% to 70% of the requirement for a primary facultative pond (receiving raw wastewater).

The existence of an anaerobic stage in an open reactor is always a matter of concern, owing to the possibility of the generation of bad odours. If the system is well balanced, the generation of bad smell should not be important, but occasional operational problems can lead to the release of hydrogen sulphide (H_2S), responsible for obnoxious odours. If the sulphate concentration in the influent is lower than 300 mg/L, the production of sulphide should not be problematic (in anaerobic conditions, sulphate is reduced to sulphide). Additionally, if the pH in the pond is close to neutrality, most of the sulphide will be present in the form of the bisulphide ion (HS^-), which is odourless (Mara et al, 1997). Wastewaters with low pH val- ues (industrial effluents or wastewater originated from a water that is soft, with low alkalinity, high acidity or without pH correction) may induce odour problems. As a result of the points above, the anaerobic-facultative ponds system should be located far away from houses (during all the operational life of the ponds).

3.1.2.2. Description of the process in anaerobic ponds

In a simplified way, the anaerobic conversion takes place in two stages:

- liquefaction and formation of acids (through the acid-forming bacteria, or acidogenic bacteria)
- formation of methane (through the methane-forming organisms, or methanogenic archaea)

In the first phase, there is no BOD removal, just the conversion of the organic matter to other forms (simpler molecules and then acids). It is in the second stage that BOD is removed, with the organic matter (acids produced in the first stage) be- ing converted mainly to methane and carbon dioxide. The carbon is removed from the liquid medium by the fact that the methane (CH_4) escapes to the atmosphere.

The methane-forming organisms are very sensitive to the environmental conditions. If their reproduction rate is reduced, there will be the accumulation of the acids formed in the first stage, with the following consequences: (a) interruption of the BOD removal process and (b) generation of bad odours, because the acids are very fetid.

Therefore, it is essential that the appropriate balance between the two com- munities is guaranteed, ensuring the completion of both stages. For the adequate development of the methane-forming archaea, the following conditions should be met:

- absence of dissolved oxygen (methane-forming archaea are *strict anaerobes* and do not survive in the presence of dissolved oxygen)
- adequate temperature of the liquid (above 15 $^{\circ}$C)
- adequate pH (close to or above 7)

The anaerobic activity affects the nature of the solids, in such a way that, in the facultative pond, the solids are less prone to fermentation and flotation, besides decomposing more easily.

3.1.2.3. Facultative ponds

Facultative ponds operate with both aerobic and anaerobic zone. Aerobic conditions are generally maintained in the upper layers while anaerobic conditions exist towards the bottom. Facultative ponds are normally characterized by:

- the effluent received: Facultative ponds are normally receiving ponds where only domestic influent is received.
- the colour of the wastewater contained within the pond is normally that of the influent received. Sometimes the colour is bluish to green depending on the algal population present.

3.1.2.4. Factors affecting pond activity

Many climatic conditions affect overall pond activity, over none of which the operator has control (Figure 1-2). However, through careful planning, one can take advantage of seasonal changes and produce a quality effluent.

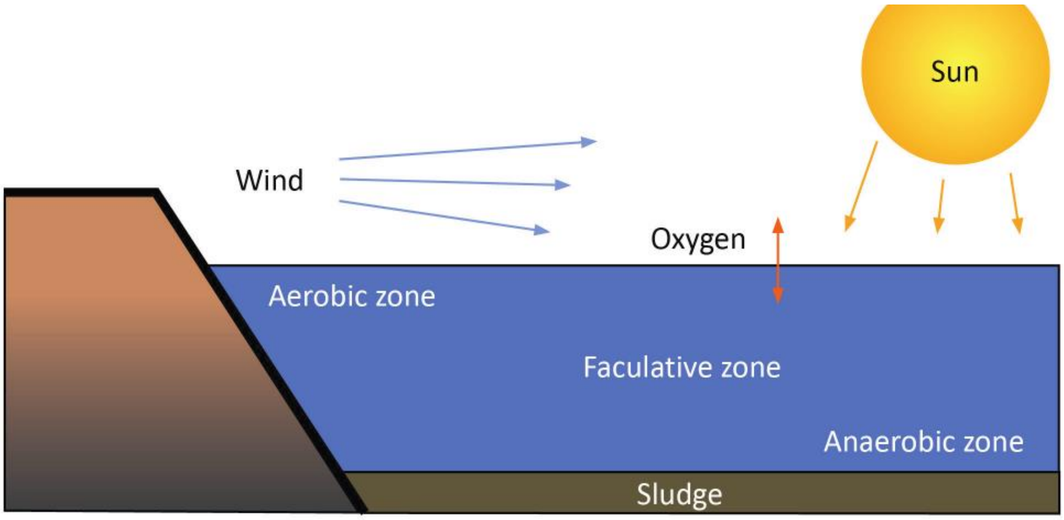


Figure 3-4: Climate Conditions Affecting Pond Activity

3.1.2.5. Influence of wind action

The amount of oxygen taken in from the atmosphere at the pond surface (when related to the total oxygen supplied for biomass respiration) is important only under certain conditions. Day-to-day, wind action adds a very small amount of oxygen. However, when the long detention times in a pond system are considered, wind action may account for a considerable amount of oxygen. When the dissolved oxygen level is below the saturation point for a given water temperature, more oxygen may be taken in at the water-air interface. In addition, if wind agitates the pond surface, the water can take up oxygen more easily.

Normally, stabilization ponds are not subject to wave action like natural lakes. This is because of their smaller size and the lower surface tension caused by detergents in the wastewater, particularly in primary ponds. During periods of rapid algae photosynthesis, oxygen in the ponds becomes super saturated. (Super saturation is an unstable condition in which the water holds more oxygen than is normal at that particular temperature). When this happens, wind action can actually remove oxygen from the water – a process called *de-aeration*.

During the summer when ponds are super saturated with oxygen, the major effect of the wind is to mix the oxygen rich water in the upper portion of the pond. Mixing by the wind

3.1.2.6. Influence of light

Because the process of photosynthesis relies on light, light is indispensable in the production of oxygen in the stabilization process. Three different, but related considerations help determine how well a pond operates and the area and depth needed for proper operation.

I. Latitude, elevation and cloud cover causes a regional variation in the amount of sunlight received during a year. Normally, for most of Minnesota, the amount of annual sunshine is about 50 to 60 percent of the total possible.
II. More importantly, seasonal change in Minnesota affects the amount of daily sunlight. Normally, summer sunshine is about 70 percent of the total possible; winter sunshine about 40 to 50 percent of the total possible.
III. How deep light can enter a pond determines how much of the pond participates in making oxygen. It also determines the best pond depth for optimum operation. Up to 30 percent of sunlight is lost when it reflects off the pond surface; more is lost when wind roughens the pond surface. How deep light penetrates the pond also depends on the amount of algae in the pond; the more algae, the less light penetrates. The amount of algae in a pond varies seasonally and from pond to pond. Studies have shown that at pond depths of more than three feet, the amount of oxygen produced is less than the amount needed. Water deeper than three feet must get oxygen by vertical mixing from wind action. For all these reasons, the best depth for operating a pond is between two and six feet.

3.1.2.7. Influence of temperature

Pond temperature changes with the seasons and the amount of sunlight it receives. Generally, as temperature decreases, the rate of biochemical oxygen demand (BOD), the kind and amount of algae, the amount of bacterial activity and the rate of respiration all decrease as well.

The only thing that increases is the dissolved oxygen saturation value; colder water can hold more oxygen. Just before and after ice cover, water holds almost twice as much oxygen as it does in summer. When ice is not present and before algae begins to grow, the amount of oxygen taken in at the pond surface is an important source to supply oxygen demand during cold weather.

3.1.2.8. Influence of nutrients

Enough nutrients must be available in a stabilization pond to support a healthy biological community of bacteria and algae. Municipal wastewater usually contains enough carbon, nitrogen, phosphorus and trace nutrients to support algal growth. In theory, aerobic treatment requires a BOD to nitrogen to phosphorus ratio of 100:5:1. The ratio in domestic wastewater is generally 100: 17:5, indicating that adequate nutrients are available. If the municipal wastewater contains a large volume of industrial waste that lacks these nutrients, the operator may need to add nutrients to make sure the biological growth and treatment processes take place.

3.1.2.9. Daily fluctuations

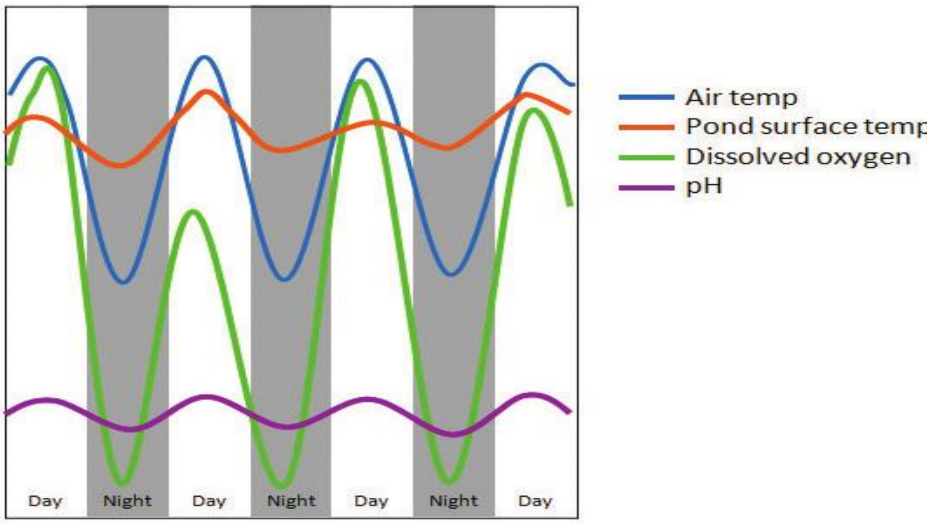


Figure 3-5: Daily fluctuation in a stabilization pond

Changes in sunlight and air temperatures over 24-hour period cause daily variations in pond temperature, dissolved oxygen concentration, pH, and other characteristics, as shown in Figure 4-5. Daily highs in dissolved oxygen may be 200 percent of saturation, while nighttime lows may approach zero. Daily fluctuations in pH, reaching as high as 10 during the day, are connected to the amount of carbon dioxide the algae use in the photosynthesis process:

1. Photosynthesis produces dissolved oxygen and uses up carbon dioxide.
2. Removing carbon dioxide reduces the acidity of the water.
3. As the acidity is reduced, the pH rises.

How much the pH rises depends upon the overall water hardness and alkalinity. The higher the hardness, the higher the pH will rise. The greater the alkalinity, the more resistance there will be to a change in pH.

3.1.2.10. Maturation ponds

Maturation ponds receive the effluent from the facultative ponds and their size and number depends on the required bacteriological quality of the final effluent. They are shallower than facultative ponds with a depth in the range 1−1.5 m, with 1 m being optimal (depths of less than 1 m encourage rooted macrophytes to grow in the pond and so permit mosquitoes to breed). Because of the lower organic loadings received by maturation ponds, they are well oxygenated throughout their depth.

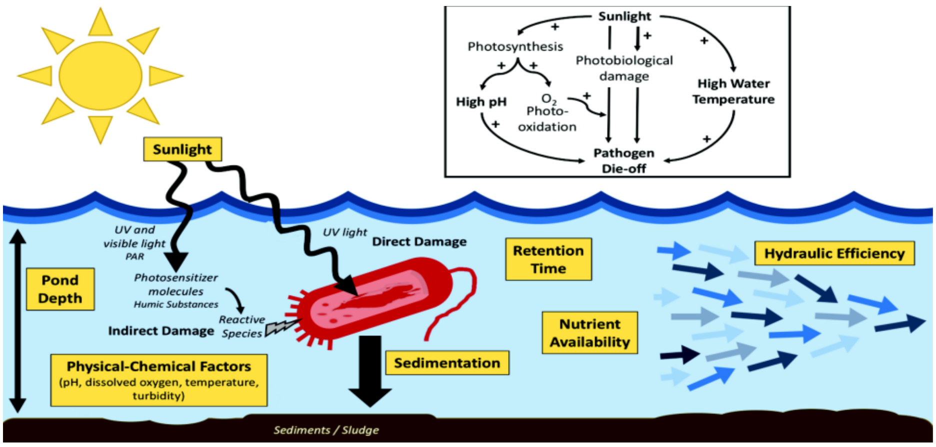


Figure 3-6: Maturation Ponds activity

The algal populations are much more diverse than that in facultative ponds; algal diversity increases from pond to pond along the series.

Maturation ponds only achieve a small additional removal of BOD_5, but they make a significant contribution to nitrogen and phosphorus removal. Total nitrogen removal in a whole WSP system is often above 80 percent and ammonia removal are generally more than 90 percent (these figures depend on the number of maturation ponds included in the WSP system). Phosphorus removal in WSPs is lower (usually about 50 percent). Examples of WSP series (anaerobic ponds + facultative ponds + maturation ponds).

- Main objective of maturation ponds is to remove FC.
- The UV portion of sunlight directly damages pathogen genomes.
- In order to ensure the sunlight penetration in maturation ponds these are kept about 1 m deep.
- Most bacterial pathogens are vulnerable to high pH. At peak algae activity, the pH of water can rise to above 9, leading to Fecal Coliform (FC) inactivation and promoting ammonia volatilization (ammonia gas).

3.1.3. Design Criteria of WSP

Designing a wastewater stabilization pond system requires meticulous planning and evaluation of various parameters to ensure an efficient, reliable, and effective treatment process. Here are some of the primary criteria to be considered

3.1.3.1. Type and Characteristics of Wastewater

The first step in designing a stabilization pond system is understanding the characteristics of the influent wastewater. The quantity, quality, and variability of the wastewater, including parameters like Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), and pathogen content, play a crucial role in defining the system's design criteria.

3.1.3.2. Climate Conditions

Local climate and weather conditions significantly impact the biological and chemical processes in the ponds. Regions with a warm climate promote better biological activity leading to efficient treatment, while colder climates may slow down the processes. Sunlight availability is critical as it promotes photosynthetic activity in facultative and maturation ponds. Seasonal variations should also be factored into the design process.

3.1.3.3. Pond Geometry and Sequence

The number of ponds and their sequence (Anaerobic, Facultative, and Maturation) are determined based on the wastewater characteristics and the desired effluent quality. Each type of pond provides a unique treatment level, and the configuration can be adapted to achieve the required treatment objectives. The depth of the ponds varies with the type of pond: anaerobic ponds are the deepest, followed by facultative and then maturation ponds.

At a minimum, stabilization pond systems should contain three ponds: two primary ponds and one secondary pond. For flexibility, the primary ponds are arranged to allow the ponds to operate in either series or parallel. A two-pond system may be allowed if the horizontal surface area of dikes (toe-to-toe) of a three-pond system is greater than or equal to the pond water surface area. If a proposed system is a two-pond system (one primary and one secondary), the total overall size of both ponds cannot exceed ten acres. The ten acres is measured at the mean operating depth. There must be an adequate elevation difference between primary and secondary ponds to allow gravity filling of the secondary pond. The secondary pond bottom elevations must be at least four feet lower than the primary pond bottom elevations. If sufficient elevation difference is not available, a pump must be provided with sufficient capacity to remove at least six inches per day from the upstream pond.

In the pond system, the secondary pond must have a capacity of one-third the volume of the entire system and able to operate in series with the primary pond(s). This means that in a two-pond system where both ponds are equal depth, the primary pond should be twice as big as the secondary. For a three-pond system and larger, all ponds should be at least equal in capacity. The secondary pond is a storage pond used in preparation for discharge.

Secondary ponds are of particular value in reducing the carryover of algae and nutrients as well as wastewater bacterial counts. Secondary pond size is important because of the time needed to complete all the necessary discharges. At design flow, it will take about 66 days to discharge a properly sized secondary pond three times, assuming a difference between the primary and secondary pond bottoms of at least four feet. If this distance is not available, a pump will be needed to pump six inches per day from the upstream pond.

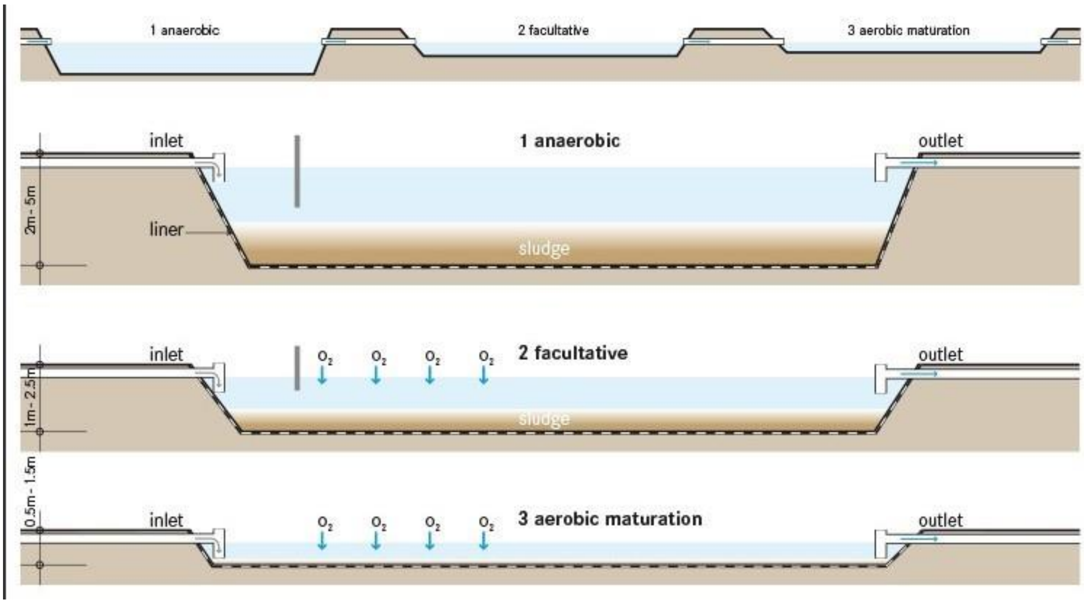


Figure 3-7: Typical Pond System

3.1.3.4. Pond bottom elevation differences

Pond system design must have an elevation difference between primary and secondary ponds that is adequate to allow the primary pond to fill the secondary pond by gravity. Secondary pond bottom elevations must be four feet lower than primary pond bottom elevations. Where this is not feasible, a portable pump and appropriate hoses must be provided. The pump must have the capacity to transfer from the upstream pond at a rate of six inches per day spread evenly over the 24-hour period.

Figure 3-8 **Elevation difference in pond bottoms**

3.1.3.5. Loading Rates and Retention Time

The design of the ponds is influenced by both hydraulic and organic loading rates. The hydraulic loading rate, given in m^3/m^2/day, influences the hydraulic retention time (HRT), which is crucial for the adequate treatment of wastewater. The organic loading rate, given in kg BOD/m^3/day, affects the ability of the microbial community to degrade organic pollutants in the wastewater.

3.1.3.6. Effluent Discharge Standards

The required level of treatment, often dictated by local or national effluent discharge standards, determines the complexity and size of the pond system. More stringent discharge standards may require a more complex system or additional treatment stages.

The design criteria, defined in the Punjab Environmental Quality Standards for Municipal and Liquid Industrial Effluents (No SO(G)/EPD/7-26/2013) published in 2016 is applicable in Punjab. The important parameter for the design of the WWTP are as depicted in Table below.

According to the Punjab Environmental quality standards for discharge of treated municipal and industrial sewage into the natural water bodies should be treated as per the quality standards (PEQS) as given below:

Table 3-1: Treatment targets effluent WWTP (according to Punjab EQS 2016)

SR. NO	PARAMETER	UNIT	NEQs (Into inland waters)
1	Temperature increase	C°	≤ 3
2	PH		06 to 9
3	TSS	mg/l	200
4	TDS	mg/l	3500
7	COD	mg/l	150
8	BOD_5	mg/l	80
9	Oil & Grease	mg/l	10
10	Phenol	mg/l	0.1
11	Cadmium (Cd)	mg/l	0.1
12	Chromium (Cr)	mg/l	1
13	Copper	mg/l	1
14	Iron	mg/l	8
16	Mercury	mg/l	0.01
17	Chlorides	mg/l	1000
18	Fluoride	mg/l	10
20	Led .Pb	mg/l	0.5
22	Ammonia NH3	mg/l	40
23	Manganese	mg/l	1.5
24	Sulphate	mg/l	600
25	CN	mg/l	1
26	Zn	mg/l	5
27	Arsenic. AS	mg/l	1
28	Lead Pb	mg/l	0.5
30	Nickel(Ni)	mg/l	1
31	Total toxic metals	mg/l	2
32	Chlorine	mg/l	1

3.1.3.7. Land Availability

Stabilization pond systems typically require a considerable land area. The availability and cost of land are important considerations when choosing to use a pond system for wastewater treatment.

3.1.3.8. Design Temperature

The design temperature is the mean temperature of the coldest month.

3.1.3.9. Design of Anaerobic ponds

- Ponds receive volumetric organic loadings in the range of 100 to 350 g BOD5/m3 day, depending on the design temperature.
- They are sized according to their "volumetric organic loading", which means the quantity of organic matter, expressed in grams of BOD5 per day, applied to each cubic metre of pond volume.
- The volumetric BOD loading (λv, g/m3 d) is given by: $\lambda_v = L_i Q / V_a$ & $V_a = L_i Q / \lambda_v$
- where L_i is the BOD_5 of the raw wastewater (mg/l = g/m3), Q is the wastewater flow (m3/d) and V_a is the anaerobic pond volume (m3).
- The permissible range of λv is g/m3.d at mean temperature of the coldest month as

Table 3-2: The permissible range of λv

Temperature(°C)	Volumetric loading (g/m$^{3)}$
10	100
10-20	20T-100
20-25	10T+100

For *domestic sewage*, the hydraulic detention time is usually within the following range:

In conventional anaerobic ponds (in which the inlet pipe is above the sludge layer), if the detention time is lower than 3.0 days, the methane-forming organ- isms may be washed out of the reactor. In these conditions, the maintenance of a stable bacterial population would not be possible. Apart from the efficiency of the anaerobic pond being reduced, the more serious aspect of imbalance between the acid-forming and methane-forming stages would occur. The consequences would be the accumulation of acids in the liquid, with the generation of bad odours, as a result of the small population of methane-forming organisms to continue the conversion of acids.

However, there is a recent tendency of decreasing the detention times in anaerobic ponds to around **2 days** and, possibly, 1 day. For this, it is necessary to increase the retention time of the biomass and to allow an intimate biomass–wastewater contact. These conditions can be obtained with the distribution of the influent in the bottom of the pond, at several points, aiming at approaching the working principle of an upflow anaerobic sludge blanket reactor. When entering the pond, the influent sewage has direct contact with the anaerobic biomass, optimising the important aspect of the organic matter – biomass contact. Traditional anaerobic ponds that presented operational problems showed an improvement in the perfor- mance and a reduction of odour generation with the simple change of the inlet pipe to the bottom of the pond.

With detention times greater than 6 days, the anaerobic pond can behave occa- sionally as a facultative pond. This is undesirable, because the presence of oxygen is fatal for the methane-forming organisms. *Anaerobic ponds must work as strict anaerobic ponds and cannot alternate between anaerobic, facultative and aerobic conditions*.

After calculating the volume based on the volumetric loading rate (L_V), the resulting detention time is obtained by: t = V/Q

where:
t = detention time (d)

V = volume of the pond (m^3)

Q = average influent flow (m^3/d)

3.1.3.10. Depth of anaerobic ponds

The depth of anaerobic ponds is high, in order to guarantee the predominance of anaerobic conditions, avoiding the pond to work as a facultative pond. In fact, the deeper the pond, the better. However, deep excavations tend to be more expensive. Values usually adopted are in the range of:

H = 3.5 m to 5.0 m

When there is no previous grit removal, the anaerobic pond could have an additional depth of at least 0.5 m, close to the inlet and extending to at least 25% of the area of the pond. However, it is believed that the inclusion of grit chamber units is beneficial, because they minimise problems of grit accumulation close to the inlet pipe and due to their simplicity.

3.1.3.11. Geometry (length / breadth ratio)

Anaerobic ponds are square or slightly rectangular, with typical length/breadth (L/B) ratios of:

Length / breadth ratio (L/B) = 1 to 3

3.1.3.12. Effluent Bod Concentration from The Anaerobic Pond

There are still no conceptual mathematical models in widespread use that allow an estimation of the effluent BOD concentration from anaerobic ponds. For this rea- son, these ponds have been designed mainly according to empirical criteria. Mara (1997) proposed the BOD removal efficiencies as a function of the temperature presented in Table 3-3 and illustrated in Figure 3-8.

Table 3-3: BOD removal efficiencies in anaerobic ponds as a function of the temperature

Mean air temperature of the coldest month - T (°C)	BOD removal efficiency E (%)
10 to 25	2T + 20
> 25	70

Source: Mara (1997)

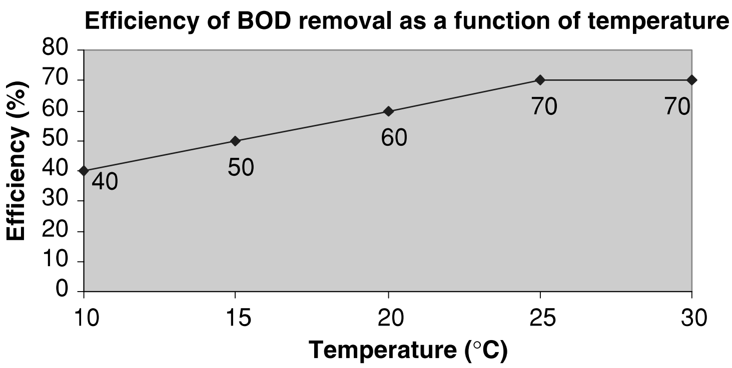


Figure 3-8: Efficiency of BOD removal

Once the removal efficiency (E) has been estimated, the effluent concentration (BOD_{effl}) of the anaerobic pond is calculated using the formulas:

$E = (S_o - BOD_{effl}).100/S_o$

$BOD_{effl} = (1 - E/100).S_o$

where:

S_o = influent total BOD concentration (mg/L)

BOD_{effl} = effluent total BOD concentration (mg/L)

3.1.3.13. Design of Facultative ponds

The influent wastewater enters at one end of the pond and leaves at the opposite end. During this time, which takes several days, a series of mechanisms contribute to the purification of the wastewater. These mechanisms occur in three zones of the ponds, denominated: *anaerobic zone, aerobic zone* and *facultative zone*.

The suspended organic matter (*particulate BOD*) tends to settle, constituting the bottom sludge (**anaerobic zone**). This sludge undergoes a decomposition pro- cess by anaerobic microorganisms, being slowly converted into carbon dioxide, methane and others. After a certain period, practically only the inert fraction (non- biodegradable) remains in the bottom layer. The hydrogen sulphide generated does not cause malodour problems, since it is oxidised by chemical and biochemical processes in the upper aerobic layer.

The dissolved organic matter (*soluble BOD*), together with the small suspended organic matter (*finely particulate BOD*) does not settle and remains dispersed in the liquid mass. In the upper layer, an **aerobic zone** is present. In this zone, the organic matter is oxidised by aerobic respiration.

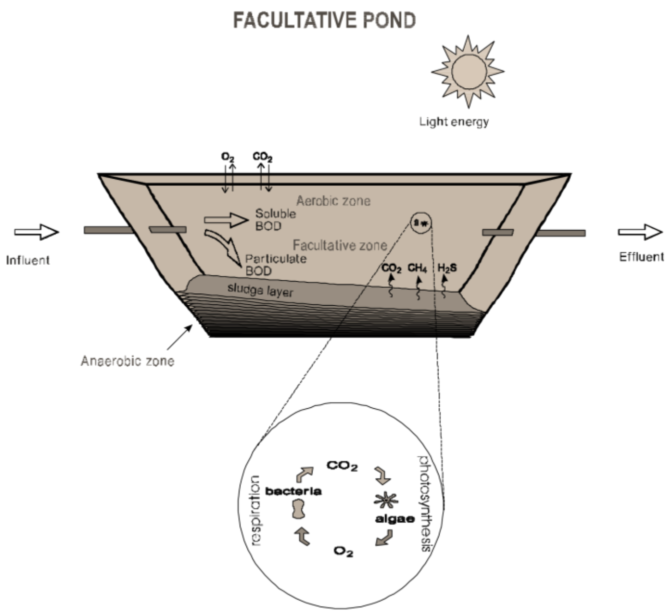


Figure 3-9: Simplified Working Principle of a Facultative Pond

Oxygen is required, which is supplied to the medium by the photosynthesis undertaken by algae, and there is a balance between the consumption and production of oxygen and carbon dioxide:

Bacteria → *respiration*:

- Consumption of oxygen
- Production of carbon dioxide

Algae → *photosynthesis*:

- Production of oxygen
- Consumption of carbon dioxide

It should be highlighted that the reactions of *photosynthesis* (production of organic matter) and *respiration* (oxidation of the organic matter) are similar, but with opposite directions:

- Photosynthesis:
  $CO_2 + H_2O$ + Energy → organic matter + O_2
- Respiration:
  Organic matter + O_2 → $CO_2 + H_2O$ + Energy

For the occurrence of photosynthesis, a source of *light energy* is necessary, in this case, represented by the sun. For this reason, localities with high solar radiation and a low level of cloudiness are highly favorable for facultative ponds.

Since photosynthesis depends on solar energy, it reaches higher levels close to the pond surface. Deeper down in the pond, light penetration is smaller, which causes the predominance of the oxygen consumption (respiration) over its production (photosynthesis), with the occasional absence of dissolved oxygen from a certain depth. Besides, photosynthesis only occurs during the day (sun- shine hours), and during the night, the absence of oxygen can prevail. Because of these facts, it is essential that there are several groups of bacteria, responsible for the stabilization of the organic matter, which can survive and proliferate in the *presence* as well as in the *absence* of oxygen. In the absence of free oxygen, other electron acceptors are used, such as nitrates (anoxic conditions). This zone, where the presence or the absence of oxygen can occur, is called a **facultative zone**. This condition also gives the name to the ponds (facultative ponds).

As commented, the process of facultative ponds is essentially natural and does not need any equipment. For this reason, the stabilization of the organic matter takes place at slow rates, implying the need of a high detention time in the pond (usually greater than 20 days). Photosynthesis, to be effective, requires a high exposure area for the best use of the solar energy by the algae, justifying the need of large units. Consequently, the total area required by facultative ponds is the largest amongst all the wastewater treatment processes (excluding land disposal systems). On the other hand, the fact that they are a natural process is associated with a larger operational simplicity, which is a factor of fundamental importance in developing countries.

The effluent from a facultative pond has the following main characteristics (CETESB, 1989):

- green color due to the algae
- high dissolved oxygen concentration
- high suspended solids concentration, although these practically do not settle

  (the algae practically do not settle in the Imhoff-cone test)

3.1.3.14. Influence of Algae

Algae play a fundamental role in facultative ponds. Their concentration is much higher than that of bacteria, giving the greenish appearance of the liquid at the pond surface. In terms of dry suspended solids, their concentration is usually lower than 200 mg/L, although in terms of numbers they can reach counts in the range of 10^4 to 10^6 organisms per ml (Arceivala, 1981). The presence of algae is usually measured in the form of chlorophyll a, a pigment presented by all plants, and the main parameter for the quantification of the algal biomass (Kö̈nig, 2000). The chlorophyll a concentrations in facultative ponds depend on the applied load and temperature, but are usually located in the range from 500 to 2000 μg/L (Mara et al, 1992).

The main types of algae found in stabilisation ponds are (Mara et al, 1992; Silva Jr. and Sasson, 1993; Jordão and Pessoa, 1995):

- **Green algae** (Chlorophyta) and pigmented flagellated (Euglenophyta). These algae give the pond the predominant greenish colour. The main genera are *Chlamydomonas*, *Chlorella* and *Euglena*. *Chlamydomonas* and *Euglena* are usually the first to appear in the pond, tending to be dominant in cold periods, and possessing flagella, which gives them motility (op- timisation of their position with relation to the incidence of light and to temperature).
- **Cyanobacteria** (previously called Cyanophyta or blue-green algae). In reality these organisms present characteristics of bacteria and algae, and are classified as bacteria. The cyanobacteria do not have locomotion organelles, such as cilia, flagella or pseudopodes, but are capable of moving by sliding. The nutrient requirements are very small: the cyanobacteria can proliferate in any environment that has at least CO_2, N_2, water, some minerals and light. These organisms are typical of conditions with low pH values and low nutrient availability in the wastewater. This environment (not typical in stabilisation ponds) is unfavourable for the green algae, which may also serve as food for other organisms, such as protozoa, leading to the proliferation of the cyanobacteria. *Oscillatoria*, *Phormidium*, *Anacystis* and *Anabaena* are among the main genera that can be mentioned.

Other types that can be found are algae of the phyla Bacyllariophyta and Chrys- ophyta (König, 2000; Mara et al, 1992). The predominant species vary from place to place, and even with the position in the series of ponds (facultative ponds and maturation ponds).

The algae photosynthesise during the hours of the day that are subject to light radiation. In this period, they produce the organic matter necessary for their sur- vival, converting the light energy into condensed chemical energy in the form of food. During the 24 hours of the day, they respire, oxidising the organic matter produced, and release the energy for growth, reproduction, locomotion and others. The balance between oxygen production (photosynthesis) and consumption (res- piration) widely favours the former. In fact, the algae may produce about 15 times more oxygen than they consume (Abdel-Razik, 1991), leading to a positive balance of DO in the system.

Owing to the requirement of light energy, most of the algae are located close to the pond surface, a location of high oxygen production. When deepening down into the pond, the light energy decreases, therefore reducing the algal concentration. In the surface layer, under 50 cm, is the range of higher light intensity, with the rest of the pond being practically dark.

There is a position in the pond depth in which the oxygen production by the algae equals the oxygen consumption by the algae and the decomposing micro- organisms. This point is called **oxypause.**

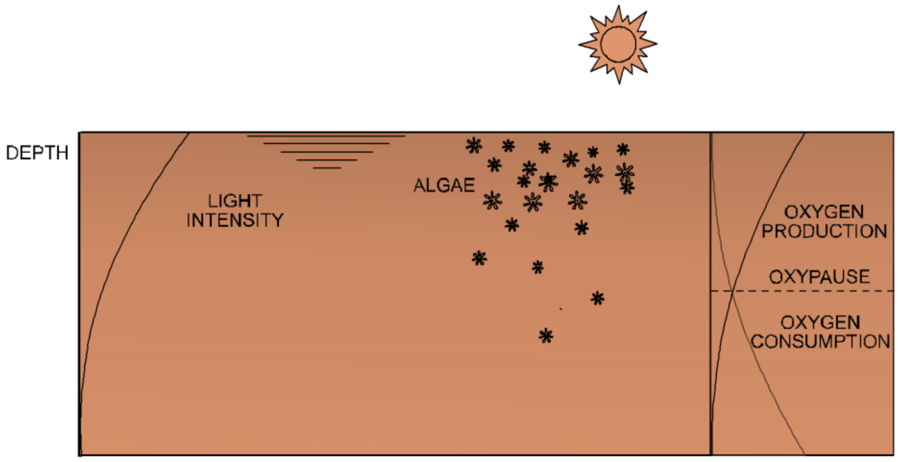


Figure 3-10: Algae, Light and energy as a function of depth

Above the exopause, aerobic conditions prevail, while below it, anoxic or anaerobic conditions predominate. The level of the exopause varies during the 24 hours of the day, as a function of the variability of the photosynthesis during this period. At night, the exopause level rises in the pond, while during the day it lowers down.

The thickness of the aerobic zone, besides varying along the day, also varies with the loading conditions of the pond. Ponds with a greater BOD load tend to have a larger anaerobic layer, which can practically take up the whole pond depth during the night. Figure 13.4 schematically illustrates the influence of the loading conditions on the thickness of the aerobic layer.

The pH in the pond also varies with the depth and along the day. The pH depends on the photosynthesis and respiration, according to:

- *Photosynthesis:*
  - Consumption of CO_2
  - Bicarbonate ion (HCO^-) of the wastewater is converted to OH^-
  - pH rises
- *Respiration:*
- Production of CO_2
- Bicarbonate ion (HCO^-_3) of the wastewater is converted to H^+
- pH decreases

  During the day, in the hours of maximum photosynthetic activity, the pH can reach values around 9 or even more. In these conditions of high pH, the following phenomena can occur:

- Conversion of the ammonium ion (NH^+_4) to free ammonia (NH_3), which is toxic, but tends to be released to the atmosphere (nutrient removal)
- Precipitation of the phosphates (nutrient removal)
- Conversion of sulphide (H_2S), which may cause bad odours, to the odourless bisulphide ion (HS^-). At pH levels greater than 9 there is practically no H_2S.

Table 3-4: Influence of the Main External Environmental Factors

Factor	Influence
Solar radiation	• Photosynthesis velocity
Temperature	• Photosynthesis velocity • Bacterial decomposition rate • Gas solubility and transfer • Mixing conditions
Wind	• Mixing conditions • Atmospheric reaeration (*)

(*) Mechanism of lesser importance in the DO balance in facultative ponds

The main parameters for the design of facultative ponds are:

- Surface organic loading rate
- Depth
- Detention time
- Geometry (length / breadth (L/B) ratio)

Surface organic loading rate. The surface organic loading rate (organic load per unit area) is the main design criterion for facultative ponds. It is based on the need to have a certain exposure area to the sun light in the pond, so that the process of photosynthesis may take place. The objective of guaranteeing photosynthesis and algal growth is to have enough oxygen production to counterbalance the oxygen demand. Thus, the surface loading rate criterion is associated with the need of oxygen for the stabilisation of the organic matter. Therefore, the surface loading rate is related to the activity of *algae* and the balance between oxygen production and consumption.

Depth. The depth has an influence on the physical, biological, and hydrodynamic aspects of the pond. After obtaining the value of the surface area (through the adoption of a value for the surface loading rate) and adopting a value for the depth, the volume of the pond is obtained.

The design parameters are basically empirical. For the surface loading rate, there are some mathematical models that allow the design of facultative ponds based on conceptual methods, such as algae production as a function of the solar radiation, oxygen production per unit algal mass and others. However, such methods are outside the scope of the present book, where the approach is essentially simplified. Besides this, the empirical methods have been traditionally used, based on experience acquired in several areas of the world.

3.1.3.15. Surface organic loading rate

- Regions with warm winter and high sunshine **Ls=240 to 350 kg BOD_5/ha.d**
- Regions with moderate winter and sunshine **Ls=120 to 240 kg BOD_5/ha.d**
- Regions with cold winter and low sunshine **Ls =100 to 180 kgBOD_5/ha.d**

3.1.3.16. Minimum retention time in Facultative ponds

- The mean hydraulic retention time (θ, days) in an individual WSP is given by: θ = *V*/*Q* (or *AD*/*Q*)

  where *V* is the pond volume (m3), *Q* the wastewater flow through the pond (m3/d), *A* is the pond area (m2) and *D* is the pond working liquid depth (m).

3.1.3.17. Land requirement of facultative ponds

- Actual formula for surface loading is $Ls=350(1.107 - 0.002T)^{T-25}$
- Total BOD_5 load is=A= 10*LiQ/λ*s

- *T is the mean air temperature of the coldest month*

3.1.3.18. Sludge accumulation in anaerobic pond

Design criteria for sludge accumulation rate is 0.03-0.1m^3 per year per inhabitant.

- Annual accumulation=Population × accumulation rate
- Accumulation be maximum 1/3 of pond depth
- Anaerobic ponds need to be desludged when they are around one-third full of sludge. This occurs every 2−5 years, but it is operationally better to remove some sludge every year.
- Facultative ponds store any sludge for their design life, which is a significant operational advantage.

3.1.3.19. Land requirement Maturation Ponds

- Area of maturation= Am =2Qiθm /(2D+0.001eθm)
- e=evaporation rate mm/day.
- D- depth range is 0.8 to 1.2 meters
- θm =Retention time varies from 3-5 day

3.1.3.20. Land requirement for Sludge drying beds

- The drying beds area should be ~0.025 m^2/person.
- Total area required for the ponds, including embankments, urbanization, internal roads, laboratory, parking and others, is about 25% to 33% greater than net area calculated (Arceivala)

3.2. Floating wet lands

3.2.1. Overview of Treatment Wetlands

Treatment wetlands are natural treatment technologies that efficiently treat many different types of polluted water. Treatment wetlands are engineered systems designed to optimise processes found in natural environments and are therefore considered environmentally friendly and sustainable options for wastewater treatment. Compared to other wastewater treatment technologies, treatment wetlands have low operation and maintenance (O&M) requirements and are robust in that performance is less susceptible to input variations. Treatment wetlands can effectively treat raw, primary, secondary or tertiary treated sewage and many types of agricultural and industrial wastewater. This volume focuses on domestic wastewater treatment using treatment wetlands.

Treatment wetlands can be subdivided into surface flow and subsurface flow systems.

Subsurface flow treatment wetlands are subdivided into Horizontal Flow (HF) and Vertical Flow (VF) wetlands depending on the direction of water flow. In order to prevent clogging of the porous filter material, HF and VF wetlands are generally used for secondary treatment of wastewater. VF wetlands for treating screened raw wastewater have also been introduced and successfully applied. These so-called French VF wetlands provide integrated sludge and wastewater treatment in a single system and thus save on construction costs, because primary treatment of wastewater is not required. Free Water Surface (FWS) wetlands (also known as surface flow wetlands) are densely vegetated units, in which the water flows above the media bed. In subsurface flow wetlands, the water level is kept below the surface of a porous medium such as sand or gravel. FWS wetlands are generally used for tertiary wastewater treatment.

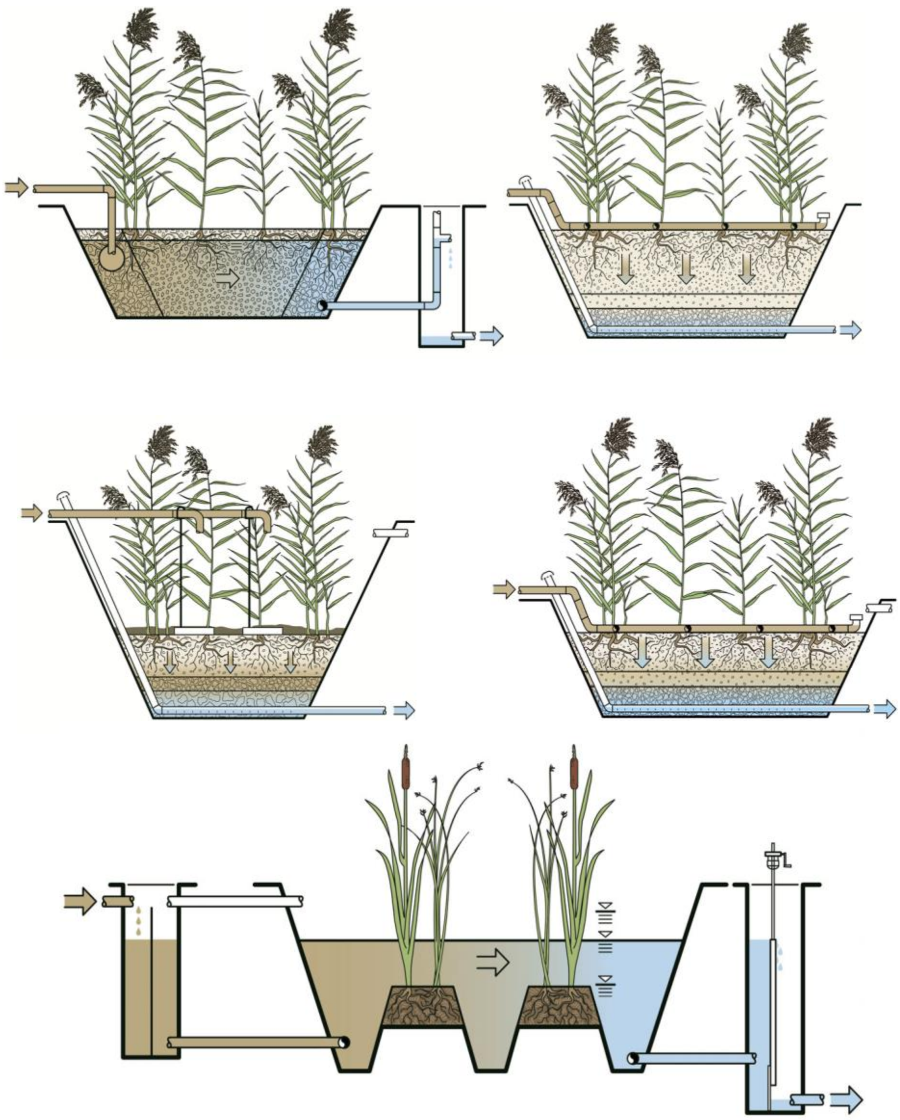


Figure 3-11: Overview schematics of treatment wetlands addressed in this volume. Top left: horizontal flow; top right: vertical flow; middle left: French vertical flow, first stage; middle right: French vertical flow, second stage; bottom: free water surface.

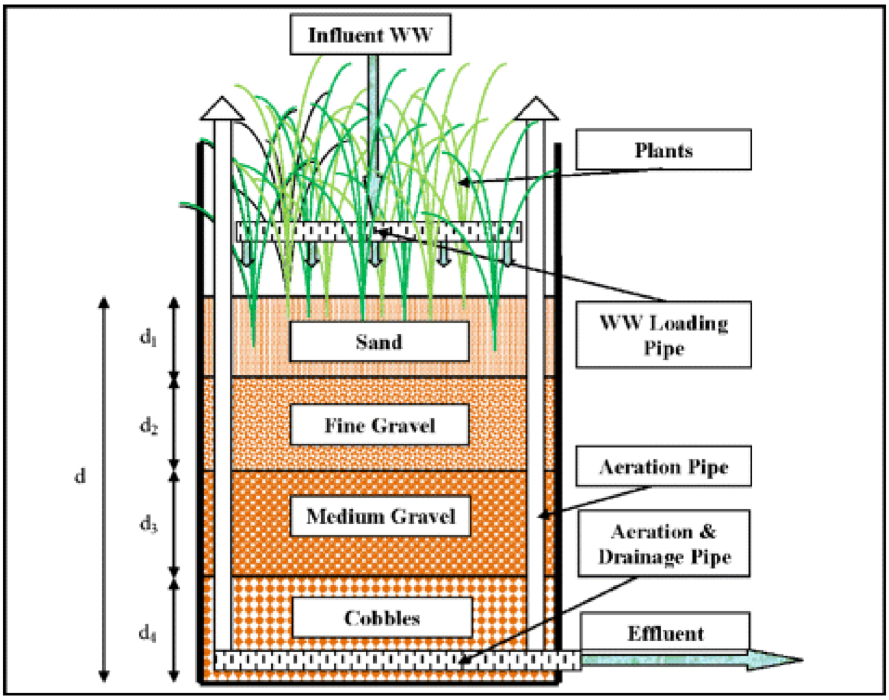


Figure 3-12: Schematic of constructed wet land

3.2.2. Floating Treatment Wetlands

Floating treatment wetlands represent a group of wetland technologies where a buoyant structure is used to grow emergent macrophytes on a pond, lake, river or similar water body. Although the early applications of floating treatment wetlands date back to the early 1990s, the development and implementation of the technology has grown rapidly in recent decades. Floating treatment wetlands lend themselves to providing ancillary benefits, such as enhancement of habitat and aesthetic values. Applications of floating treatment wetlands include:

- Stormwater
- Polluted water canals
- CSO
- Sewage
- Acid mine drainage
- Animal production effluent
- Water supply reservoirs

A floating treatment wetland consists of emergent wetland vegetation growing on a mat or structure that floats on the surface of a pond-like water body (Headley and Tanner, 2012). The plant stems remain primarily above the water surface, while their roots grow down through the buoyant structure and hang in the water column (Figure8.4). The plants grow essentially in a hydroponic manner, taking the majority of their nutrition directly from the water column. A hanging network of roots, rhizomes and attached biofilm forms beneath the floating mat, which provides a biologically active surface area for biochemical processes to occur as well as physical processes such as filtering and entrapment of particulates. Thus, a general design objective is often to maximise the contact between the root-biofilm network and the polluted water passing through the system. The depth of root penetration will depend largely on the plant species used and the physio-chemical conditions that develop in the water column below the floating plants.

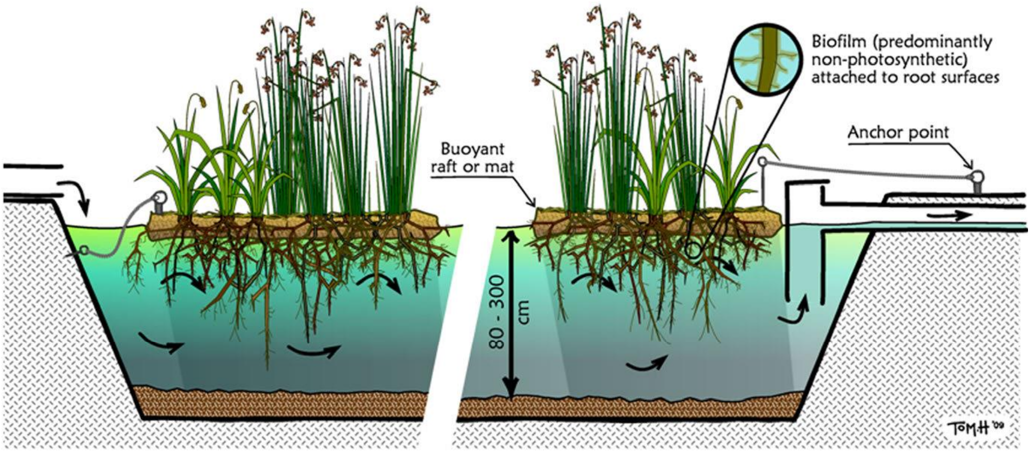


Figure 3-13: Schematic of a Typical Floating Treatment Wetland System

Naturally occurring floating marshes exist in many parts of the world, where the right combination of factors has led to their development. However, the natural processes that lead to autonomous formation of large self-buoyant mats of emergent macrophytes are relatively slow and difficult to control. Thus, floating treatment wetlands are typically constructed using a floating raft or mat structure onto which suitable emergent macrophytes are planted. These are often modular in design, so that smaller, manageable individual units are joined together as needed to form larger rafts. A range of materials has been used for creating the floating rafts, including bamboo or plastic pipes and fabricated buoyant plastic mats made specifically for supporting floating wetland plants in a pond environment. The various construction techniques vary in cost, durability and effectiveness.

3.2.3. Treatment Mechanism:

Treatment wetlands are complex wastewater treatment systems possessing a diverse set of pollutant and pathogen removal pathways. Unlike other conventional wastewater treatment systems in which removal processes are optimised by a series of separate unit operations designed for a specific purpose, multiple removal pathways simultaneously take place in one or two reactors.

3.2.3.1. Physical Processes:

Here, the physical presence of roots and the mat structure plays a crucial role. As wastewater moves around and through these obstacles, particles and suspended solids can become trapped and settle. Over time, these solids can be colonized by beneficial microbes and gradually broken down. Additionally, many contaminants are adsorbed directly onto roots and mat substrates, effectively removing them from the water column.

3.2.3.2. Biological Processes:

Roots provide a rich environment for diverse microbial communities. These microbes metabolize and degrade many organic contaminants, converting them into less harmful substances or even into basic elements like carbon dioxide. The plants themselves also play a vital role, drawing nutrients directly from the wastewater. This process not only nourishes the plants but also removes nutrient pollutants.

3.2.3.3. Chemical Processes:

The rhizosphere, or the region surrounding plant roots, is a chemically active zone. Here, reactions mediated by microbial processes can transform pollutants. For instance, metals might be precipitated as non-soluble forms, or toxic compounds might be broken down into simpler, less harmful molecules.

Table 3-5: Chemical Processes

Parameter	Main removal mechanisms
Suspended solids	Sedimentation, filtration
Organic matter	Sedimentation and filtration for the removal of particulate organic matter, biological degradation (aerobic and/or anaerobic) for the removal of dissolved organic matter
Nitrogen	Ammonification and subsequent nitrification and denitrification, plant uptake and export through biomass harvesting
Phosphorus Pathogens	Adsorption-precipitation reactions driven by filter media properties, plant uptake and export through biomass harvesting
Parameter	Sedimentation, filtration, natural die-off, predation (carried out by protozoa and metazoa)

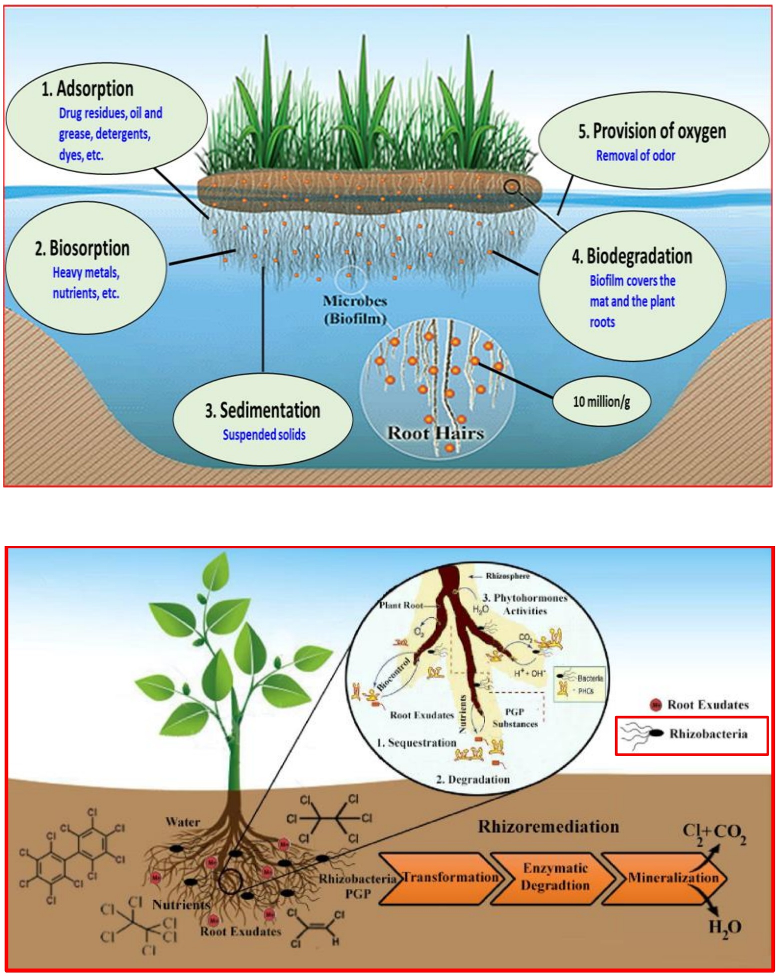


Figure 3-14: Enhanced Remediation

3.2.4. Types of Floating Mats

Floating mats are foundational to these systems:

3.2.4.1. Non-Buoyant Mats

Rooted in a more natural approach, these mats are made from permeable materials and rely entirely on the buoyancy provided by the plants themselves. Over time, as plants grow and establish, these mats can become more stable and buoyant, creating a self-sustaining system.

3.2.4.2. Buoyant Mats

These mats are constructed from inherently buoyant materials such as specific plastics or foams. Engineered with openings, plants grow through these pockets, allowing roots to access the water below. Their construction ensures consistent buoyancy regardless of plant growth.

Most floating wetland designs use polyethylene, polypropylene, polyurethane or polyvinyl alcohol foam to ensure the buoyancy.

Foam Mats

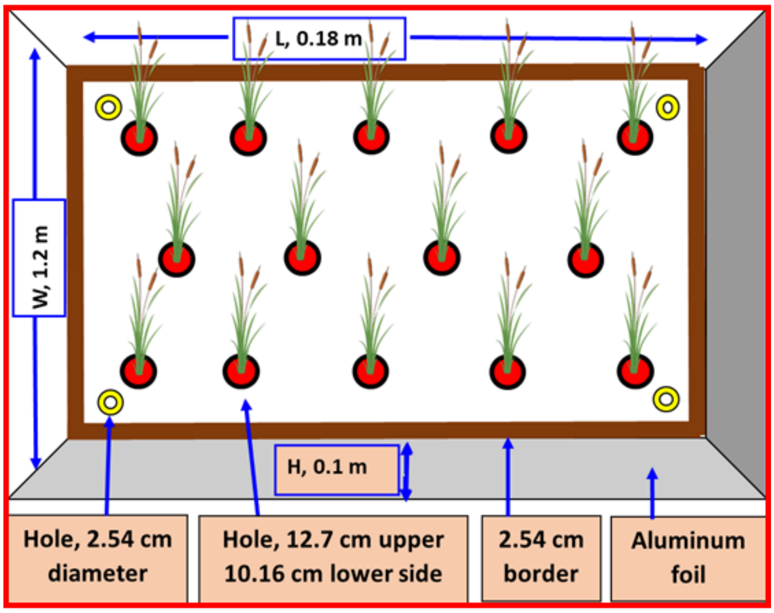


Figure 3-15: Foam Mats

3.2.4.3. Bamboo Mats

Bamboo, a naturally buoyant material, are also used to make floating rafts for growing plants in the FWT process (Rehman et al. 2019a). For example, the fresh bamboo was cut into the desired length to fit into the circular tank without obstruction. Then, a hand-made single-layer bamboo raft of 38 cm by 38 cm square in shape was used to provide floatation and to support plants (Weragoda et al. 2012). Finally, a plastic net pot of 5 cm diameter was used to hold the plants without any growth medium, and it was positioned in the bamboo raft at 10 cm maximum spacing

Figure 3-16: Bamboo Floating Raft

Figure 3-17: Plants Grown on Bamboo Floating Mats

3.2.4.4. Plastic mats

Figure 3-18: Plastic Pipe and Canes Mats

Figure 3-19: Net of polyethylene

Source: H_2Open Journal Vol 6 No 2, 173 doi: 10.2166/h2oj.2023.032

3.2.4.5. Modular Systems

These are modern innovations where individual floating units, often of geometric shapes like hexagons or squares, can be interlocked. This design offers scalability, enabling the system to expand or contract based on treatment needs.

3.2.5. Reduction of Pollution Level

a) As per research study "*Phytoremediation of domestic sewage using a floating wetland and assessing the pollutant removal effectiveness of four terrestrial plant species"conducted by Arivukkarasu D. and Sathyanathan R. Department of Civil Engineering, SRM Institute of Science and Technology, Kattankulathur, Tamil Nadu 603203, India* and published in "H2Open Journal Vol 6 No 2" the efficiency of Floating Wet Lands remained as follows:

This study demonstrated and evaluated the ability of terrestrial plant species such as C. indica, O. tenuiflorum, Ch. zizanioides, and H. rosa-sinensis in the FWT to reduce pollutant concentration levels in domestic sewage.

"The floating wetland treatment with C. indica (FWT-CI) was found to be the best in the removal of turbidity (92.67%), TSS (96.46%), TP (98.33%), ammonia (95.58%), and DO (45.31%) but Ch. zizanioides (FWT-CZ) showed the highest reduction for TDS (48.79%), TN (85.91%), sodium (53.13%), potassium (74.77%), phosphate (85.37%), EC (27.72%), COD (93.93%), BOD (95.11%), E. coli (47.19%), TH (30.23%), and pH (24.48%).

However, the other floating wetland system with O. tenuiflorum plant showed the highest removal for turbidity (95.33%) and also effectively removed TP (94.17%), potassium (47.08%), ammonia (84.51%), DO (43.75%), and EC (21.16%).

Additionally, FWT-HR (H. rosa-sinensis) considerably removed pollutants from the municipal sewage like turbidity (72.67%), TP (77.78%), TN (46.97%), potassium (43.85%), phosphate (65.85%), ammonia (46.02%), DO (45.31%), EC (18.22%), COD (73.35%), and BOD (78.70%). The findings of this research made it clear that terrestrial plants had the highest rate of removal of different pollutants from domestic sewage, empha- sizing that C. indica and Ch. zizanioides have significant potential for treating domestic wastewater".

BOD, COD removal, and E. coli removal

"Microorganisms developed on the roots and rhizomes of the plants in floating wetlands are imperative in removing organic matter from domestic wastewater. However, additional procedures, including filtration, nutrient absorption, and oxygenation, remove organic compounds from the water column. The relationship between BOD and COD is the primary factor in identifying the presence of organic matter and its degradability. According to earlier studies, BOD/COD ratio greater than 0.5 contains a more incredible amount of organic matter. In the present study, this ratio ranged between 0.3 and 0.8, indicating the absence of toxic components and the readiness in biodegradable conditions (Shahid et al. 2018).

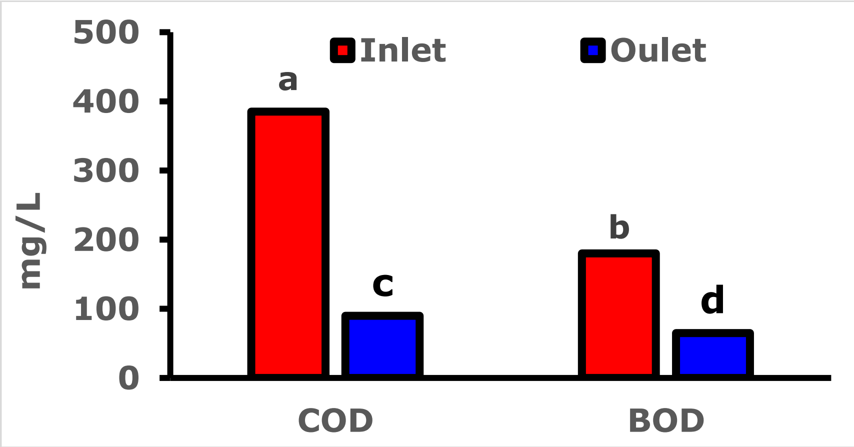
When domestic sewage was treated using C. indica and vetiver plants, the concentration of BOD was dramatically reduced to 4.5 mg/L. Among all four FWT systems, BOD removal efficiency during the HRT of 0–25 days was the maximum for ***FWT-CZ at 95.11%. Based on the average removal rates, FWT-CI (average 88.28%) . FWT- OT (average 87.21%) . FWT-CZ (average 83.55%) . FWT-HR (average 57.79%).*** *Among all*

FWTs, the BOD concentration was found to be statistically not significant. According to previous publications, biological oxygen demand levels were significantly lowered using floating wetlands; as a result, elimination efficiency ranged from 87.2 to 95% (Prajapati et al. 2017). The results of this investigation are also consistent with earlier removal rates of BOD (93%) (Rehman et al. 2019b).

Concerning COD removal efficiency, both the C. indica and vetiver plant species showed COD removal rates of max. 92.63% and min. 64.56% (avg. 85.07%), and max. 93.93% and min. 49.09% (avg. 78.59%), respectively. In contrast, O. tenuiflorum and H. rosa-sinensis plants achieved a maximum removal efficiency of 87% and min. 80.94% (average 85.08%) and max. 73.35% and min. 12.18% (average 46.91%), respectively. Among all FWTs, the COD concentration was found to be statistically not significant. The COD removal efficiency of our study is higher than the findings of previous publications of 90% removal effi- ciency using Vetiveria zizanioides (terrestrial plant) (Rehman et al. 2019b) and an average removal of 60% using Pistia stratiotes (hydrophytes) and Eichhornia crassipes (free floating plant) (Prajapati et al. 2017; Tusief et al. 2019).

Out of four FWTs, those with C. indica and Vetiver grass considerably decreased the initial concentration of E. coli, dropping to 850 and 870 MPN/100 mL with an efficiency of 46.88 and 45.63% to other treatments. FWT-OT and FWT-HR achieved the maximum and minimum removal efficiencies of 18.44 and 16.25% and 36.81 and 18.75%, respectively, at 25 days HRT. However, vetiver and C. indica plants showed higher E. coli removal efficiencies of 47.19 and 45.63%, respectively, than the other two plant species. The E. coli concentration among all FWTs was found to be statistically significant."

b) According to Afzal, M., et al. (2019). Floating treatment wetlands as a suitable option for large-scale wastewater treatment. Nature Sustainability. 2(9):863-871.https://www.nature.com/articles/s41893-019-0350-y.the results of Sewage and Industrial Wastewater Stabilization Ponds in Faisalabad remained as follows:



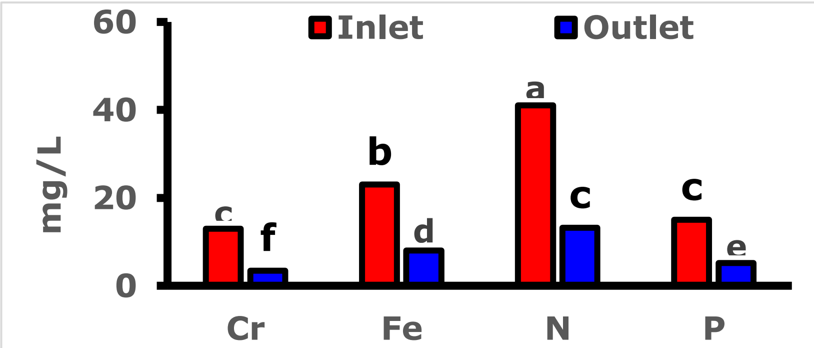


Figure 3-20: Effluent Quality

4. OPERATION AND MAINTENANCE OF STABILIZATION POND TREATMENT SYSTEM

Once the ponds have started functioning in steady state, routine maintenance is minimal but essential for good operation. The main routine maintenance activities are:

- Removal of screenings and grit from the preliminary treatment units
- Periodically cutting the grass on the pond embankments
- Removal of scum and floating macrophytes from the surface of facultative ponds and maturation ponds. This is done to maximize the light energy reaching the pond algae, increase surface re-aeration, and prevent fly and mosquito breeding
- If flies are breeding in large numbers on the scum on anaerobic ponds, the scum should be broken up and sunk with a water jet
- Removal of any material blocking the pond inlets and outlets
- Repair of any damage to the embankments caused by rodents or rabbits (or any other burrowing animals)
- Repair of any damage to fences and gates.

Further explanation of some operational measures is given below

4.1. Proper Pond Operation

Proper operation of a stabilization pond system primarily involves managing the influent and effluent flows, and periodically inspecting the ponds' physical conditions. The influent flow rate should be managed to ensure the design hydraulic retention time is achieved, and the effluent should be sampled and tested regularly to verify the system is performing as expected.

Additionally, periodic inspection of the pond embankments, spillways, inlet and outlet structures, and aeration equipment (if any) is required. The growth of vegetation on embankments should be controlled as it may damage the structure or interfere with pond operations

4.1.1. Operating a pond system in series

For a system with more than one primary in series operation, wastewater is discharged first to one of the primary pond(s). Then it is transferred in succession to each additional downstream pond in the system. Series operation is the recommended operation mode during the summer because of increased algae levels caused by excessive nutrients, sunlight, and warmer water. Series operation allows more of the solid material, including algae, to settle out before the operator transfers the semi-treated wastewater to a subsequent pond. Using a slow transfer rate (six inches per day) keeps most algae and nutrients in the upstream pond. Since algae increase the suspended solids in the effluent, minimizing algae in the transferred water will ensure water in the subsequent pond will have a lower suspended solids content.

Follow the procedures below to operate a two, three, four, or more ponds system in series. To operate a two-pond system in series:

I. Shut off all control structures or valves, to prevent water from flowing between the primary and secondary pond. (The discharge structure must be closed.)

II. Create old water by holding it in the primary pond. When water depth in the primary pond is one foot more than the depth in the secondary pond, transfer six inches per day from the primary to secondary. (The discharge structure from the secondary pond must be closed.)

III. Continue to make old water and transfer six inches per day from the primary to secondary pond each time the primary is one foot deeper than the secondary.

To operate a system greater than two ponds in series:

I. Shut off all control structures or valves to prevent water from flowing between the primary and secondary ponds. (The discharge structure must be closed.)
II. Divert all influent flow into one of the primary ponds. (To avoid solids from building up, each year alternate influent flow between the primary ponds.)
III. When water in this primary is one foot deeper than the other primary(s), transfer six inches of water per day from one primary to the other primary.
IV. Continue to make old water. When water depth in last primary is a foot more than the secondary pond, transfer six inches per day from last primary to the secondary. (The discharge structure must be closed.)
V. From then on, continue to make old water and transfer water each time the water in a pond is one foot deeper than the downstream pond.

Notes: When using series operation for three or more ponds, only transfer between two ponds at a time to reduce the potential for short-circuiting between ponds. Short- circuiting is when water bypasses the normal flow path and reaches the outlet in less than the normal detention time, not allowing time for sufficient treatment.

• A transfer rate of six inches per day (measured from the upstream pond) is recommended because it is slow enough to avoid transferring solids, particularly phosphorus, to the downstream pond. Excessive phosphorus will increase algae growth.

• Do not allow the secondary to remain at a depth of less than three feet for an extended period. Keeping the secondary at a depth of three feet or more will avoid excessive weed growth during the summer.

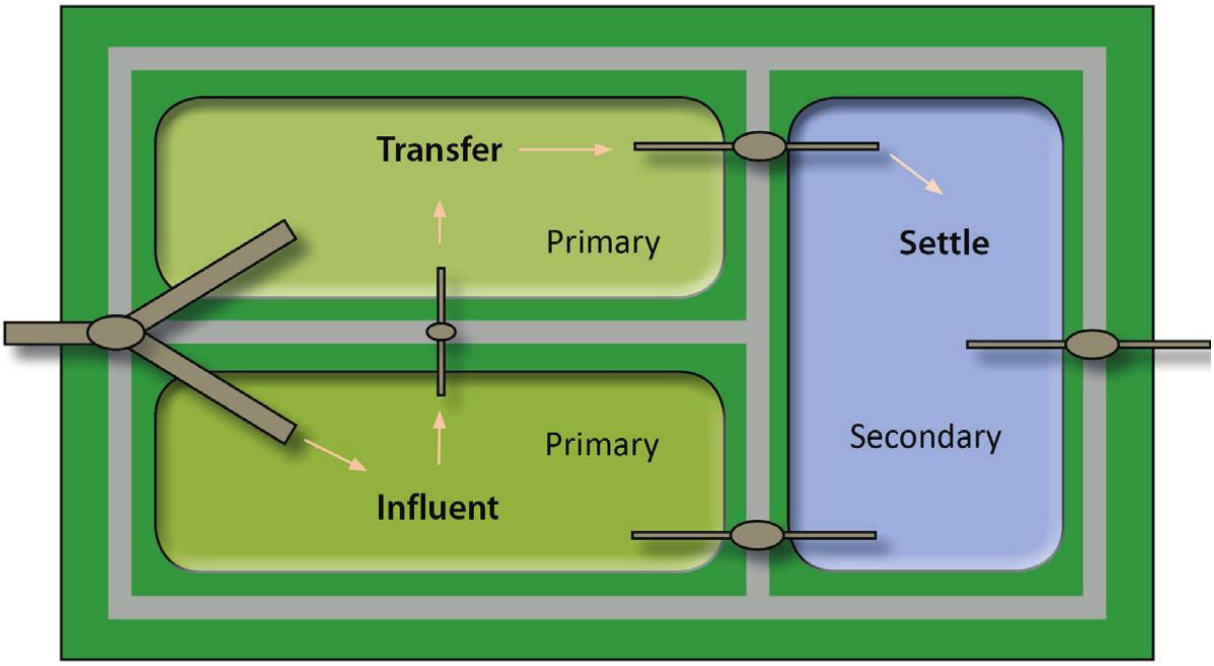


Figure 4-1: Three-cell System Operating in Series

4.1.2. Operating a pond system in parallel

To operate in parallel, influent wastewater is discharged equally to all primary ponds by splitting the influent flow and loading equally. Parallel is the recommended operation type during winter because the overall pond system is usually anaerobic. Parallel operation distributes the solids and organic loading over a larger area, providing more treatment area when the pond is ice covered and biological activity is low. Distributing the CBOD loading helps avoid organic overload to one pond. (Note: a two-pond system cannot be operated in parallel.)

To operate a three-pond or larger system (two primary ponds and one secondary) in parallel:

I. Shut off all control structures or valves to prevent flow between all ponds. (The discharge structure must be closed.)

II. Equally, split influent flow and loading between all primary ponds.

III. Create old water by holding it in all the primary ponds. When water in a primary pond is one foot deeper than in the secondary pond, transfer six inches per day from that primary pond to the secondary.

IV. After that, continue to make old water and then transfer water each time the water in a primary is one foot deeper than in the secondary.

Notes:

A transfer rate of six inches per day is recommended because it is slow enough to avoid having solids, particularly phosphorus, transferred to the downstream pond. Excessive phosphorus will increase algae growth.

Do not allow the secondary to remain at a depth less than three feet for an extended period of time. Keeping the secondary at a depth of three feet or more will avoid excessive weed growth during the summer.

4.1.3. Transferring water between ponds

When transferring water between ponds, follow these steps:

1. Create old water within each pond.
2. Transfer no more than six inches per day from the upstream pond.
3. As soon as possible, fill the secondary pond to a depth of at least three feet to avoid weed problems in the summer.
4. Isolate the secondary pond at least 30 days before the first discharge or irrigation. After that, you will need to isolate for only three to four days.

Elevation difference

- A properly designed stabilization pond system should have at least a four-foot elevation difference between the primary and secondary ponds (Figure 6-7). With this elevation difference, a two-foot level in the primary corresponds to a six-foot level in the secondary. After discharging from the secondary pond, the elevation difference allows the operator to discharge the primary pond and refill the secondary pond to its maximum depth entirely by gravity.
- When a pond system does not have an adequate elevation difference, the operator will need to use a portable pump to transfer water. As a guide, to pump six inches of water per day, you will need a 100 gallon-per-minute pump for every one acre of pond from which you are pumping. For example, if you need to transfer six inches of water from a six-acre pond, you will need a 600 gallon-per-minute (gpm) pump (six acres times 100 gpm per acre).
- When pumping, do not place the intake side of the piping near the bottom of the pond. Instead, use the control structure by pumping from one side of the divider wall to the other.

Figure 4-2: Elevation difference between ponds

If that is not possible, use a floatation device to support the intake piping that is just below the pond surface.

After discharging four feet from the secondary pond, if additional discharge(s) are needed, the operator will use gravity or a pump to transfer water from the primary until the secondary pond depth reaches six feet. After filling the secondary, wait three or four days to allow time for the water to clarify before taking pre-discharge samples.

Control structures

Operators use control structures to regulate water levels to reach their goal of producing old water in order to produce a quality effluent that meets all PEQS requirements. Some control structures can be used not just to control the water level, but also to measure flow and water depth, sample, as an access point for pumping, and, when necessary, to add and mix chemicals.

Water level is controlled by adjusting slide gates, valves, or similar devices in the structure. Using slide gates or a telescoping valve allows the operator to pre-select the desired water depth.

Common Pond Colour

The colour of a stabilization pond is often a good indicator of its health. Anaerobic ponds are usually black or grey due to the anaerobic conditions and the production of sulfides. Facultative ponds often exhibit a greenish color due to the growth of photosynthetic algae in the top layer. Aerobic or maturation ponds are typically clear with a slight green tint, indicating good health and efficient treatment. Any significant changes in pond colour should be investigated, as it could indicate operational problems.

Table 4-1: Common Pond Color

Pond Colour	Often indicates
Dark green	Normal primary pond operation
Light Green	Normal secondary pond operation; indicates proper transfer and reduced loading
Dark pea Soup	Sometimes occur in primary pond during summer
Black or Grey	In summer indicates overloading—too much CBOD
Blackish Green	Indicates presence of blue green algae
Red Streaks or Pink	Red Streaks are typically caused by Daphnia under stress due to inadequate oxygen level. Pink could indicate presence of purple sulfur bacteria in anaerobic condition or red algae in aerobic conditions

4.1.4. Operational Staff:

Operational staff are responsible for the daily management of the pond system, including monitoring and controlling influent and effluent flows, inspecting and maintaining pond structures, managing any aeration equipment, and testing effluent quality. They should be well trained in the principles of pond operation and the interpretation of effluent test results. In case of any problems or issues, they should be capable of identifying the cause and implementing appropriate solutions.

As a rough guide one full-time operator is required at WSPs receiving wastewater flows up to about 1,000 m3 /d, two operators for wastewaters flows up to about 2,500 m3 /d and pro rata for higher flows. A foreman/supervisor is required at sites treating more than 5,000 m3 /d; and should also keep a record of all maintenance activities, measure and record the wastewater flow and carry out routine effluent sampling.

All WSP operators should receive adequate training so that they understand what they have to do and how to do it correctly. If, for example, the pond operators have not been told to remove scum from facultative ponds and maturation ponds, they will not know that it should be removed. As a result, scum can cover a substantial part of the pond, algal photosynthesis becomes impossible, and the pond turns anoxic

4.1.4.1. Operation Start-up

Loading of the ponds

The initial loading of the ponds can be done by means of one of the two procedures described below. The loading should be performed preferably in summer, when temperatures are higher.

a) Filling of the pond with water pumped from the MC supply system

- Fill the pond with a minimum water depth, preferably reaching 1 m.
- Close the outlet devices.
- Begin the introduction of sewage until reaching the water depth adopted in the design.

The adoption of this procedure:

- prevents the uncontrolled growth of vegetation, which occurs in conditions of low water depth;
- allows testing of the watertightness of the system;
- enables the correction of occasional problems resulting from a deficient compaction (before the introduction of sewage).

b) Filling of the pond with a mixture of water pumped from MC water supply system and wastewater to be treated

• Mix the wastewater and the water (dilution at a ratio equal to or greater than 1/5)

- Fill up the pond to a depth of approximately 0.40 m
- Await some days, until the appearance of algae is visible
- In the subsequent days, add more wastewater, or wastewater/water mixture, until algal blooming occurs
- Interrupt feeding for a period of 7 to 14 days
- Fill up the pond with wastewater until the operation level
- Interrupt the feeding
- Await the establishment of a population of algae (around 7 to 14 days)
- Feed the pond normally with the wastewater

  Should no water be available, the ponds can be filled up with raw sewage and left for about 3 to 4 weeks, in order to allow the development of the microbial population. Some odour release will be unavoidable in this period (Mara et al, 1992).

  The whole loading period should be monitored by operators with experience in the process. The total loading period can last 60 days, until a balanced biological community is established in the medium.

The following two procedures should be avoided:

- the slopes, accumulating decomposable solids and releasing Feed with the wastewater load adopted in the design, but without a balanced biological community established in the pond. If this happens, the pond will suffer from anaerobiosis, with release of bad odours. The reversal of the anaerobiosis process can take two months.
- Feed the ponds with small, continued loads, which frequently occur when there are few housing connections. In this case, as the soil is not clogged yet, the liquid could percolate through bad odours.

4.1.4.2. Beginning of operation of anaerobic ponds

The beginning of the operation of anaerobic ponds requires the following procedures:

- Begin the introduction of sewage according to the recommendations in Section above.
- Maintain the pH of the medium slightly alkaline (7.2 to 7.5). To facilitate the occurrence of these conditions, digested sludge from sewage treatment plants or from Imhoff tanks, or limestone, vegetable ash or sodium bicarbonate can be added after 30 days of operation.
- Anaerobic ponds should be started-up after the facultative ponds. This avoids the release of odours from the discharge of anaerobic effluents into an empty facultative pond. Should the concentration of raw sewage be very low, or its flow be small in the beginning of the operation of the system, it would be better to divert the raw sewage to the facultative pond, until a volumetric organic load of at least 0.1 kgBOD/m .d is reached in the anaerobic pond (Mara et al, 1992). If there is more than one anaerobic pond in parallel, only one pond could be loaded, so that the load applied to this pond is the same as or higher than the minimum value of 3 0.1 kgBOD/m .d.

4.1.4.3. Beginning of operation of facultative ponds

The following procedures are recommended (CETESB, 1989):

- Begin the introduction of sewage according to the recommendations of Section above.
- The maintenance of a slightly alkaline pH should happen naturally, in case the recommendations of Section above are followed.
- Measure the dissolved oxygen daily.

4.1.4.4. Beginning of operation of ponds-in-series systems

The ponds located downstream of the primary pond can be started-up according to the following recommendations (CETESB, 1989):

- Begin the filling of the ponds when the water depth in the primary pond reaches a minimum value of 1.0 m.
- Close the outlet devices of the ponds.
- Water should be added to the ponds until a depth of 1.0 m is reached.
- When the primary pond reaches the operational level, its effluent can be directed to the subsequent cell, taking the following precautions:
    - Remove the stop-logs slowly, preventing the water depth of the previous unit from dropping below 1.0 m
    - Do not perform bottom discharge operations from the primary cell
    - Equalise the water depth in all ponds slowly

- Avoid the situation in which a pond is totally full, while the subsequent unit is empty

4.1.5. Main Operational Problems of Anaerobic Ponds and their Possible Solutions:

Operational problems with anaerobic ponds can include excessive odour production, pond crusting or scum formation, and overloading.

Table 4-2: Main operational problems of anaerobic ponds and their possible solutions

Problem: bad odours
Causes • Sewage overload and small detention time • Very low load and an excessively high detention time (the pond behaves as a facultative one, with the presence of DO in the liquid) • Presence of toxic substances • Abrupt fall of the wastewater temperature
Prevention and control measures • Recirculate the effluent from the facultative or maturation pond to the inlet of the anaerobic pond (recirculation ratio of approximately 1/6) • Improve the distribution of the influent to the pond (distribution by perforated tubes on the bottom of the pond) • In case of overload apply occasional partial by-pass to the facultative pond (if it supports the increased load) • In the case of long detention times, operate with only one anaerobic pond (if there are two or more ponds in parallel) • Add sodium nitrate to several points of the pond • Add lime (~12 g/m^3 of the pond) to raise the pH, reducing the acid conditions responsible for • the inhibition of methanogenic organisms and for the larger presence of sulphide in the free, toxic form • Add products that remove sulphides • Avoid the addition of chlorine, because it will cause subsequent problems to the restart of the biological activities
Problem: proliferation of insects
Causes • Screened material or sand removed not conveniently disposed of • Growth of vegetation where the water level is in contact with the internal slope • Oil and scum layer always present • Poor maintenance

Prevention and control measures   1. Bury the material removed from the screens and grit chambers   2. Cut the grown vegetation   3. Revolve, with a rake or water jet, the layer of floating material that covers the ponds   **4.** Apply carefully insecticides or larvicides to the scum layer
Problem: growth of vegetation
Causes   Inadequate maintenance
Prevention and control measures   • Aquatic vegetation (that grows on internal slopes): total removal, preventing it from falling in the pond   • Terrestrial vegetation (that grows on external slopes): remove weeds from the soil; add chemical products for control of weeds
Problem: green patches where the water level is in contact with the slope
Causes   • Proliferation of algae, in view of the small depth in the water level-slope section
Prevention and control measures   • Remove the algae colonies
Problem: surface of the pond covered with a scum layer
Causes   • Scum, oils and plastics
Prevention and control measures   • No measure needs to be taken: the scum layer is totally normal in anaerobic ponds, helping to maintain the absence of oxygen, to control the temperature and to hinder the release of bad odours

4.1.6. Main operational problems of facultative ponds and their possible solutions

Table 4-3: Operational Problems of Facultative Ponds

Problem: scum and floating material (preventing the passage of light energy)
Causes   • Excessive blooming of algae (forming a greenish surface)   • Discharge of unwanted material (e.g.: rubbish)   • Sludge lumps released from the bottom   • Little circulation and wind influence

Prevention and control measures
• Break the scum with water jets or with a rake (broken scum usually sinks) • Remove the scum with cloth sieves, burying it later • Break or remove the sludge lumps • Remove physical obstacles to penetration of the wind (if possible)
Problem: bad odours caused by overload
Causes
• Overload of sewage, causing lowering of the pH, reduced DO concentration, change in the effluent colour from green to yellowish green (predominance of rotifers and crustaceans, which eat algae), appearance of grey zones close to the influent, and bad odours
Prevention and control measures
• Change the operation of the ponds from serial to parallel • Remove temporarily the problematic pond from operation (provided there are at least two ponds in parallel) • Recirculate the effluent at a ratio of 1/6 • Consider the adoption of multiple inlets, to avoid preferential paths • In case of consistent overloads, consider the inclusion of aerators in the pond • Add occasionally sodium nitrate, as a supplementary source of combined oxygen
Problem: bad odours caused by poor atmospheric conditions
Causes
• Long periods with cloudy weather and low temperature
Prevention and control measures
• Reduce the water depth • Put a pond in parallel in operation
Problem: bad odours caused by toxic substances
Causes
Toxic substances from industrial discharges, generating sudden anaerobic conditions in the pond
Prevention and control measures
• Perform a complete physical–chemical analysis of the influent, in order to identify the possible toxic compound • Identify, in the catchment area, the industry causing the discharge, taking the measures provided for by the legislation • Isolate the affected pond • Place a second unit in parallel in operation, provided with aeration, if possible
Problem: bad odours caused by hydraulic short circuits
Causes
• Poor distribution of the influent • Dead zones resulting from the excessive utilisation of the contours when shaping the pond • Presence of aquatic vegetation in the pond

Prevention and control measures • Collect samples at several points in the pond (e.g.: DO) to verify whether there are significant differences from one point to another • In case of multiple inlets, provide a uniform distribution of influent flow in all inlets • In case of a simple inlet, build new inlets • Cut and remove aquatic vegetation
Problem: high concentrations of algae (SS) in the effluent
Causes • Environmental conditions that favour the growth of certain algae populations
Prevention and control measures • Remove the effluent submerged through baffles, which retain the algae • Use multiple cells in series, with a small detention time in each cell • Undertake the post-treatment of the effluent from the pond, to remove excessive SS
 **Summer Algae**
• **Problem: proliferation of insects**
Causes • Presence of vegetation on the internal slopes of the ponds in contact with the water level
Prevention and control measures • Reduce the water level, causing the larvae trapped in the vegetation of the slopes to disappear when the area dries • Operate the pond with variation in the water level • Protect the internal slope with concrete plates, reinforced mortar, geomembrane, etc • Place fish in the pond, such as carps • Destroy the scum • Apply chemical products judiciously
Problem: vegetation inside the pond
Causes • Low operational level of the pond (below 60 cm) • Excessive seepage • Low wastewater flow

Prevention and control measures
• Operate the ponds with a level higher than 90 cm • Cut the vegetation on the internal borders, preventing it from falling in the ponds • Protect the slope internally with concrete plates, reinforced mortar, rip-rap, geomembranes, etc • Remove the vegetation inside the pond with canoes or dredges (lower the water level to facilitate the operation)

4.2. Troubleshooting

Troubleshooting in a stabilization pond system often involves identifying changes in effluent quality or pond conditions (like colour or odour), determining the cause, and implementing a solution. Common causes of problems can include changes in the influent load or characteristics, equipment failure, structural problems, or changes in environmental conditions. Solutions might involve adjusting influent flows, repairing or replacing equipment, repairing structures, or adjusting operational procedures. Regular monitoring and prompt attention to any identified problems are crucial to maintain the system's effective operation.

When you have problems for which you don't have a solution, try the following:

Table 4-4: Weeds and Trees

Problem	Observation	Harmful effect	Probable cause	Possible solution
Cattails and bulrushes	Excessive growth along dikes in shallow water area; usually in water less than 3 ft deep	Damages seal • Reduces circulation • Provides insect habitat • Encourages muskrats • Causes short-circuiting • Reduces wind action	• Low water level • Lack of proper maintenance • Seed crop of cattails or bulrushes close to ponds	•Pull new growth • Lower water level and cut; then raise water 3 ft above the top of the plant • Spray with approved herbicide • Remove dead vegetation
Small trees	Normally found on dike in shallow water or on dikes	• Roots are deep penetrating and will damage seal • Reduces wind action • Provides insect & muskrat habitat • Produces unsightly appearance • Weakens dike compaction	Lack of proper maintenance	•Pull new growth •Frequently mow new growth • Spray older trees to kill; cut and remove trees • Apply granular brush killers to roots if water at tree base is shallow
Duck weed	• Clover- like floating plant • Looks like velvety green carpet • Shallow roots • Singular or three-leaf types	• Thick mats may hinder sunlight penetration • Less than 50% coverage usually not a problem • Thick mats may rot and cause odors	• Normal July through September • Comes from duck wings • Warmer water • Quiet water; lack of wind action	• Check pond DO; if more than 5 mg/L, should not cause problem • Increase wind action by removing weeds, trees, etc. • Skimming helps short term (7-10 days) • Herbicides may help short term

Problem	Observation	Harmful effect	Probable cause	Possible solution
				• Normally dies off with cool fall nights

Figure 4-3: Cattail

4.3. Operation and Maintenance of Wetlands

Wetlands are "natural" systems. As a result, operation is mostly passive and requires little operator intervention. Operation involves simple procedures similar to the requirements for operation of a facultative lagoon. The operator must be observant, take appropriate actions when problems develop, and conduct required monitoring and operational monitoring as necessary. The most critical items in which operator intervention is necessary are adjustment of water levels

- Maintenance of flow uniformity (inlet and outlet structures)
- Management of vegetation
- Odor control
- Control of nuisance pests and insects
- Maintenance of berms and dikes

4.3.1. Water Level and Flow Control

Water level and flow control are usually the only operational variables that have a significant impact on a well- designed constructed wetland's performance. Changes in water levels affect the hydraulic residence time, atmospheric oxygen diffusion into the water phase, and plant cover. Significant changes in water levels should be investigated immediately, as they may be due to leaks, clogged outlets, breached berms, storm water drainage, or other causes.

4.3.2. Maintenance of Flow Uniformity

Maintaining uniform flow across the wetland through inlet and outlet adjustments is extremely important to achieve the expected treatment performance. The inlet and outlet manifolds should be inspected routinely and regularly adjusted and cleaned of debris that may clog the inlets and outlets. Debris removal and removal of bacterial slimes from weir and screen surfaces will be necessary. Submerged inlet and outlet manifolds should be flushed periodically. Additional cleaning with a high-pressure water spray or by mechanical means also may become necessary.

Influent suspended solids will accumulate near the inlets to the wetland. These accumulations can decrease hydraulic detention times. Over time, accumulation of these solids will require removal.

4.3.3. Vegetation Management

Routine maintenance of the wetland vegetation is not required for systems operating within their design parameters and with precise bottom-depth control of vegetation. Wetland plant communities are self-maintaining and will grow, die, and regrow each year. Plants will naturally spread to unvegetated areas with suitable environments (e.g., depth within plant's range) and be displaced from areas that are environmentally stressful. Operators must control spreading into open water areas that are intended by design to be aerobic zones through harvesting.

The primary objective in vegetation management is to maintain the desired plant communities where they are intended to be within the wetland. This is achieved through consistent pretreatment process operation, small, infrequent changes in the water levels, and harvesting plants when and where necessary. Where plant cover is deficient, management activities to improve cover may include water level adjustment, reduced loadings, pesticide application, and replanting.

Harvesting and litter removal may be necessary depending on the design of the system. Plant removal from some wetlands may be required to meet the treatment goals, but a well-designed and well-operated FWL system should not require routine harvesting. Harvesting of plants at the height of the growing season and just before the end of the growing season does help to remove some nitrogen from the system, but phosphorus removal is limited (Suzuki et al., 1985).

4.3.4. Odor Control

Odors are seldom a nuisance problem in properly loaded wetlands. Odorous compounds emitted from open water areas are typically associated with anaerobic conditions, which can be created by excessive BOD and ammonia loadings. Therefore, reducing the organic and nitrogen loadings can control odors. Alternatively, aerobic open water zones interspersed in areas between fully vegetated zones introduce oxygen to the system. Turbulent flow structures such as cascading outfall structures and channels with hydraulic jumps, which are employed to introduce oxygen into the system effluent, can generate serious odor problems through stripping of volatile compounds such as hydrogen sulfide, if the constructed wetland has failed to remove these constituents.

4.3.5. Control of Nuisance Pests and Insects

Potential nuisances and vectors that may occur in FWS wetlands include burrowing animals, dangerous reptiles, mosquitoes, and odors. An infestation of burrowing animals such as muskrats and nutria can seriously damage vegetation in a system. These animals use both cattails and bulrushes as food and nesting materials. These animals can be controlled during the design phase by de- creasing the slope on berms to 5:1 or using a coarse riprap. Temporarily raising the operating water level may also discourage the animals. Live trapping and release may be successful, but in most cases it has been necessary to eliminate the animals. Fencing has had little success.

4.3.6. Maintenance of Berms and Dikes

Berms and dikes require mowing, erosion control, and prevention of animal burrows and tree growth. If the trees are allowed to reach maturity, they may shade out the emergent vegetation and with it the necessary conditions to enhance flocculation, sedimentation, and denitrification.

4.3.7. Plant Health:

Plants are the heart of the system. Regular health checks ensure that they are growing well, free from diseases or pests, and are effectively drawing pollutants from the water.

4.3.8. Hydraulic Loading:

It's essential to control the flow rate of wastewater entering the system, ensuring that it aligns with the system's design and capacity. Too much flow can overwhelm the system, while too little can lead to stagnation.

4.3.9. Sediment Buildup:

Over time, sediment accumulation can impact water flow and reduce system efficiency. Periodic removal ensures optimal operation.

5. MAINTENANCE RECORDS AND EFFLUENT QUALITY MONITORING

5.1. Compliance with Effluent Standards and Regulations

Compliance with effluent standards and regulations is a critical aspect of wastewater treatment. Depending on the jurisdiction, certain standards must be met concerning the quality of the treated water before it can be discharged into the environment. This typically includes limits on parameters such as Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), nutrient content (nitrogen and phosphorus), and pathogen content. Regular testing of the effluent is necessary to ensure these standards are being met, and any non-compliance must be promptly addressed.

Table 5-1: Effluent standards

SR. NO	PARAMETER	UNIT	NEQs (Into inland waters)
1	Temperature increase	C°	≤ 3
2	PH		06 to 9
3	TSS	mg/l	200
4	TDS	mg/l	3500
7	COD	mg/l	150
8	BOD_5	mg/l	80
9	Oil & Grease	mg/l	10
10	Phenol	mg/l	0.1
11	Cadmium (Cd)	mg/l	0.1
12	Chromium (Cr)	mg/l	1
13	Copper	mg/l	1
14	Iron	mg/l	8
16	Mercury	mg/l	0.01
17	Chlorides	mg/l	1000
18	Fluoride	mg/l	10
20	Led .Pb	mg/l	0.5
22	Ammonia NH3	mg/l	40
23	Manganese	mg/l	1.5
24	Sulphate	mg/l	600
25	CN	mg/l	1
26	Zn	mg/l	5
27	Arsenic. AS	mg/l	1
28	Lead Pb	mg/l	0.5
30	Nickel(Ni)	mg/l	1
31	Total toxic metals	mg/l	2
32	Chlorine	mg/l	1

5.2. Principal Causes of Effluent Quality Loss

The loss of effluent quality can occur due to various factors including overloading of the system (hydraulic or organic), inadequate retention time, inadequate or ineffective treatment processes, changes in influent characteristics, structural or equipment failures, and adverse environmental conditions (like low temperatures or lack of sunlight). A thorough understanding of the system's design and operation, as well as regular monitoring and maintenance, can help prevent or quickly resolve these issues.

Potential causes and solutions of problems are summarized in the table below:

Table 5-2: Problems and solutions

Containment	Typical effluent concentration	Deviation	Potential causes	Potential solutions
TSS	10-150	>50	Algal growth Sludge build up	Out let shading Desludge
BOD	15-110	>40	Algal growth Sludge build up	Out let shading Desludge
NH4-N winter	0.5-30	>15	Cold temperature Sludge build up Low DO Overloading	Desludge Reduce load
NH4-N summer	0.1-10	>5	Sludge build up Low DO Overloading	Desludge Reduce load
DRP	2-12	>6	High influent concentration Sludge build up	Desludge
TP	4-16	>8	High influent concentration Sludge build up	Desludge
E-COLI	2000-50,000	>10,000	Short circuiting	Improve hydraulics
FC	5000-100,000	>20,000	Short circuiting	Improve hydraulics

5.3. Daily Inspection and Occurrence Record

Regular daily inspections are crucial for identifying potential issues early and maintaining the effective operation of the system. Inspections should cover all aspects of the system including the physical condition of the ponds and associated structures, operation of any equipment (like pumps or aerators), and observable characteristics of the ponds (like colour and odour). Any occurrences or changes noted during inspections should be recorded. This can help in identifying trends, troubleshooting problems, and planning for maintenance.

Daily Record Sheet

Table 5-3: Daily Record Sheet

Day---------Date--------			
Weather Conditions			
Weather (sunny, cloudy, rainy)			
Wind (none, weak, strong)			
Item	**Yes**	**NO**	**Comment / location / quantity / measures**

Observations in the pond Is there sludge rising in the pond? Are there green patches on the surface? Are there black patches on the surface? Are there oil stains on the surface? Is there vegetation in contact with the water? Is there erosion on the slopes? Is there visible seepage? Are birds present? Are insects present?			
Other aspects Are the fences in good condition? Are the stormwater ditches clean? Is the flow meter working? Have weeds been removed? Has scum been removed? Have solids been removed from the screen? Has grit been removed from grit chamber? Has there been any power failure? Has the by-pass to the receiving body been used?			

5.4. Measurement and Sampling Program:

A regular measurement and sampling program should be established to monitor the effluent quality and ensure compliance with effluent standards. This typically involves taking regular samples of the effluent and testing for various parameters. The frequency and timing of sampling can depend on the specific characteristics of the system and the influent, as well as the requirements of the local regulatory authority.

Various parameters are discussed as follows:

- **Dissolved oxygen** (DO) is the oxygen concentration existing in a solution (dissolved) with water. It is available for fish to breathe and aerobic microorganisms to utilize. If not present at certain levels, aquatic life cannot be sustained. Dissolved oxygen can be added to water in several ways: by aeration equipment, turbulent flow, algae, or wind. Whatever the mechanism, dissolved oxygen is of major importance for good wastewater treatment.
- **Temperature** – as the temperature of water rises, its ability to hold dissolved oxygen decreases. Knowing how much oxygen water can hold (determined by its temperature), plus knowing the DO value present (after conducting a DO test), will determine whether you need to add more oxygen. The farther the DO value is below the holding capacity of the water, the more oxygen you can add. At zero degrees Centigrade and at sea level, the most oxygen that will dissolve in water is 14.6 mg/L.

At 20 degrees Centigrade, the most oxygen is about 9 mg/L. However, because of excessive algal activity, stabilization ponds have been known to hold more than 14.6 mg/L (often as high as 25-30 mg/L). This condition of water holding more oxygen than normal is called super-saturation.

- **Biochemical oxygen demand** (BOD) – BOD measures the amount of oxygen needed by bacteria to decompose organic matter and some inorganic chemicals such as ammonia and nitrite under aerobic (in the presence of oxygen) conditions. Normal domestic wastewater contains about 200-250 mg/L of BOD with each person contributing about 0.17 pounds per day to the waste stream. The BOD test is conducted for a period of five days in an incubator at 20 degrees C. The higher the BOD, the more organic and inorganic pollutants are in the sample, and more oxygen is needed by the bacteria to decompose the organic material. The lower the BOD, the less pollutants in the sample; less oxygen is needed for decomposition. The term *BOD* is used both for the analysis and to describe the strength of the waste in terms of pollution potential.
- **Carbonaceous BOD** (CBOD) – CBOD analysis is similar to BOD analysis, except that before incubation, a chemical is placed into the sample bottle that inhibits the bacteria that nitrify, or break down the nitrogen compounds in the sample. This means only the remaining or carbon-based (carbonaceous) BOD will be analyzed by the test. Most pond systems in Minnesota report CBOD test results on their Discharge Monitoring Report (DMR), as nitrifying bacteria are not active in a pond system in cold weather. The CBOD test then gives a more accurate assimilation of the breakdown of organic material in a pond system.

- **Chemical Oxygen Demand** (COD) – COD analysis, relies on the oxygen used during the breakdown of the organic and inorganic compounds in a sample containing chemicals, not bacteria like the BOD test. COD does not measure the oxygen-consuming potential associated with certain dissolved organic compounds, but it will give a quick estimate of the strength of a sample, which indicates its pollution potential. A COD test takes only two hours compared to five days for a BOD test, making it much more applicable for process control. Municipal facilities that accept septage or industrial waste use the COD test to determine a waste's effect on the system before they allow it. Note that the COD test cannot be used for DMR reporting purposes.

Table 5-4: Solubility of Oxygen in Water (mg/L)

°C	°F	O_2	°C	°F	O_2
0	32.0	14.6	26	78.8	8.2
1	33.8	14.1	27	80.6	8.1
2	35.6	13.8	28	82.4	7.9
3	37.4	13.5	29	84.2	7.9
4	39.2	13.1	30	86.0	7.6
5	41.0	12.8	31	87.8	7.5
6	42.8	12.5	32	89.6	7.4
7	44.6	12.2	33	91.4	7.3
8	46.4	11.9	34	93.2	7.2
9	48.2	11.6	35	95.0	7.1
10	50.0	11.3	36	96.8	7.0
11	51.8	11.1	37	98.6	6.9
12	53.6	10.8	38	100.4	6.8
13	55.4	10.6	39	102.2	6.7
14	57.1	10.4	40	104.0	6.6
15	59.0	10.2	41	105.8	6.5
16	60.8	10.0	42	107.6	6.4
17	62.6	9.7	43	109.4	6.3
18	64.4	9.5	44	111.2	6.2
19	66.2	9.4	45	113.0	6.1
20	68.0	9.2	46	114.8	6.0
21	69.0	9.0	47	116.6	5.9
22	71.6	8.8	48	118.4	5.8
23	73.4	8.7	49	120.2	5.7
24	75.2	8.5	50	122.0	5.6
25	77.0	8.4	51	123.8	5.5

- **Total suspended solids** (TSS) – TSS represent the portion of the total solids load that is not dissolved. To determine TSS, a specific volume of sample is poured through a pre-weighed filter pad. The filter pad is weighed again after drying in an oven at 103 to 105^{O}C to remove all the water. The gain in dry weight (in milligrams) is then compared to the volume of sample (in milliliters) that was poured through the filter pad. The final results are expressed in milligrams per liter. TSS usually corresponds with BOD. If a sample tests high for TSS, the BOD usually tests high also. If the TSS result is low and the BOD result high, it may mean that the BOD is caused by dissolved organic or inorganic compounds.

Sampling program

Sampling program form for daily, weekly, Monthly and occasional is given as below:

Table 5-5: Sampling program

Frequency	Parameter	Measurem. / analysis	Influent	Facultative pond	Aerated lagoon	Effluent
Daily	Flow (m^3/d)	*In situ*	x			x
	Air temperature (°C)	*In situ*				
	Liquid temperature (°C)	*In situ*	x	x	x	x
	pH	*In situ*	x	x	x	x
	Settleable solids (mL/L)	*In situ*	x			x
	Dissolved oxygen (mg/L)	*In situ*		x	x	
Weekly	Total BOD (mg/l)	Central lab.	x			x
	Total COD(mg/l)	Central lab.	x			x
	Filtered BOD or COD (mg/L)	Central lab.				x
	Faecal coliforms (or *E. coli*) (org/100 mL)	Central lab.	x			x
	Total suspended solids (mg/L)	Central lab.	x			x
	Volatile suspended solids (mg/L)	Central lab.	x			x
Monthly	Organic nitrogen (mg/L)	Central lab.	x			x
	Ammonia (mg/L)	Central lab.	x			x
	Nitrate (mg/L)	Central lab.				x
	Phosphorus (mg/L)	Central lab.	x			x
	Sulphate (mg/L)	Central lab.	x			x
	Sulphide (mg/L)	Central lab.	x			x
	Alkalinity (mg/L)	Central lab.	x			
	Oils and greases (mg/L)	Central lab.	x			x
Occasional	Counting of zooplankton	Central lab.		x		
	Counting of phytoplankton	Central lab.		x		
	Main genera of algae	Central lab.		x		
	DO produced by photosynthesis (mg/L.h)	*In situ*		x		
	DO consumed by respiration (mg/L.h)	*In situ*		x		
	Hourly flow (m^3/h) (24h,every h)	*In situ*	x			
	Hourly DO (mg/L) (24h,every h)	*In situ*		x	x	

5.5. Information needed for a pond system

When keeping records for a pond system, include the following information:

I. **Plans and specifications**

Keep a complete set of as-built drawings of the facility available. Record and include on the drawings any changes made, such as piping and electrical changes.

II. **Operating records**

Keep records that are detailed enough to enable you to continuously evaluate collection system and pond system performance. Maintain records indicating the amount of time spent on each operation.

III. **Maintenance records**

Keep records of facility equipment, its service requirements, the service schedule, the work performed and when it was completed. To maximize usefulness, keep these records permanently:

- Equipment inventory
- Operation and maintenance instructions

- Equipment specifications from supplier
- Spare parts inventory
- Where spare parts can be purchased
- Preventive maintenance records
- Preventative maintenance schedule
- Service record cards

5.6. Suggested maintenance forms

Following two maintenance forms are suggested which, will help you keep track of equipment maintenance:

1. A preventive maintenance card (Table5-6)
2. An equipment maintenance record (Table5-7)

Make a preventive maintenance card for each piece of equipment. Each card should contain:

- The type of equipment
- The nameplate data
- The location of the equipment
- The installation date
- The approved preventive maintenance schedule
- Special lubricants specified by the manufacturer
- A reference to troubleshooting information that may be included in instruction manuals
- Space for the person doing the maintenance to initial and date the card
- Space to note any unusual problems and corrective maintenance that was done

Table 5-6: Preventive Maintenance Card

<table>
<tr><td>Equipment</td><td colspan="2">Serial number</td></tr>
<tr><td>Manufacturer</td><td colspan="2">Installation date</td></tr>
<tr><td colspan="2">Preventive maintenance</td><td>Schedule dates</td></tr>
<tr><td colspan="2"></td><td></td></tr>
<tr><td colspan="2"></td><td></td></tr>
<tr><td colspan="2"></td><td></td></tr>
<tr><td colspan="2"></td><td></td></tr>
<tr><td colspan="2"></td><td></td></tr>
<tr><td colspan="2"></td><td></td></tr>
<tr><td colspan="2"></td><td></td></tr>
</table>

Table 5-7: Equipment Maintenance Record

Equipment			**Serial number**	
Manufacturer		**Location**	**Attachments:**	
Modification/repair				
Date	Description of work done	Parts-new or required	Person hours	By

5.7. Operation and maintenance costs

Summarize operation and maintenance costs monthly. These records will help you:

- Determine the efficiency of the treatment process
- Decide spare parts inventories
- File the annual report

You may also find them useful to compare the treatment cost per million gallons of wastewater with equivalent costs from other communities of similar size. Large cost differences between communities point to inefficiencies in operation and maintenance.

Annual report

Maintaining a summary of plant performance and costs will allow you to evaluate performance and prepare a budget. Evaluate costs monthly. Then use your monthly operation records to prepare an annual summary of operating data and costs. To determine user charges, you will need records of waste loads received from industries. See an example of information that may be required in an annual report below.

Table 5-8: Annual Report for Plant Performance

Annual Report for (facility/year)____________________		
Operating data	**Notes**	**Total**
Connected population		
Flow, MGD		
Summer average		
Winter average		
Screenings (cu ft/day)		
BOD		
Influent, mg/L		

Effluent, mg/L		
% reduction		
TSS		
Influent, mg/L		
Effluent, mg/L		
% reduction		
pH		
Effluent, max		
Effluent, min		
Others		

Table 5-9: Annual Report for Cost

Cost data	Notes	Cost
Labor		
Chemicals		
Maintenance		
Supplies		
Vehicle operation		
Utilities		
Miscellaneous		
	Total costs	
	Budget	

5.8. Key Wastewater Quality Parameters to Assess Efficient Plant Operations (Floating Wet Lands)

Analyzing water quality is primarily essential for surveillance reasons. The significance of this evaluation encompasses:

- Verifying if the water quality aligns with set standards and determining its appropriateness for its intended application.
- Evaluating the effectiveness of systems that ensure water quality.
- Identifying if there's a need to upgrade or modify an existing system and determining the necessary alterations.

Hence, conducting water quality assessments is vital for securing precise outcomes. Following are some parameters which need to be monitored closely for efficient performance of plant

5.8.1. pH analysis

The pH metric, often used in tests, is vital as wastewater treatment and waste quality management heavily rely on pH.

Natural water generally has a pH between 4 and 9, mostly leaning towards the basic side due to alkali and alkaline earth metals' bicarbonates and carbonates. Various factors, from carbon dioxide balance to the bioactivity of plants, dictate the pH value. As pH plays a significant role in liquid properties, its measurement becomes crucial. Additionally, pH is a foundational element in many analytical calculations and procedures.

At a given temperature, the intensity of the acidic or basic character of a solution is indicated by pH or hydrogen ion concentration. pH values from 0 to 7 are diminishing acidic, 7 to 14 increasingly alkaline and 7 is neutral.

5.8.2. Total suspended solid (TSS)

The suspended solids in wastewater are solids that are insoluble. Typical domestic wastewater contains 200-250 mg/L of insoluble solids. Their size varies; larger particles settle easily, whereas smaller ones might not settle at all.

For TSS analysis, filter a specified wastewater amount through a pre-weighed glass fiber filter, dry it, and then weigh the residue. Findings are presented in mg/L.

5.8.3. Total dissolve solid (TDS)

TDS measures the sum of organic and inorganic substances in a liquid. Excluding pure H2O molecules, these solids mainly consist of minerals, salts, and organic materials. A high TDS often signifies hard water, which can cause scaling in pipes and appliances, leading to maintenance costs.

The filterable residue is the material that passes through a standard glass filter disk and remains after evaporation and drying at 180°C.

5.8.4. Biochemical Oxygen Demand (BOD)

The Biochemical Oxygen Demand (BOD) is an empirical standardized laboratory test which measures oxygen requirement for aerobic oxidation of decomposable organic matter and certain inorganic materials in water, polluted waters and wastewater under controlled conditions of temperature and incubation period. The quantity of oxygen required for above oxidation processes is a measure of the test. The test is applied for fresh water sources (rivers, lakes), wastewater (domestic, industrial), polluted receiving water bodies, marine water (estuaries, coastal water) and also for finding out the level of pollution, assimilative capacity of water body and also performance of waste treatment plants.

Since the test is mainly a bio-assay procedure, it is necessary to provide standard conditions of temperature, nutrient supply, pH (6.5-7.5), adequate population of microorganisms and absence of microbial-growth-inhibiting substances. The low solubility of oxygen in water necessitates strong wastes to be diluted to ensure that the demand does not increase the available oxygen. A mixed group of microorganisms should be present in the sample; otherwise, the sample has to be seeded. Generally, temperature is controlled at 20ºC and the test is conducted for 5 days, as 70 to 80% of the carbonaceous wastes are oxidized during this period.

5.8.5. Chemical Oxygen Demand (COD)

Chemical Oxygen Demand (COD) test determines the oxygen requirement equivalent of organic matter that is susceptible to oxidation with the help of a strong chemical oxidant. It is an important, rapidly measured parameters as a means of measuring organic strength for streams and polluted water bodies. The test can be related empirically to BOD, organic carbon or organic matter in samples from a specific source taking into account its limitations.

The test is useful in studying performance evaluation of wastewater treatment plants and monitoring relatively polluted water bodies. COD determination has advantage over BOD determination. COD results can be obtained in 3-4 hrs as compared to 3-5days required for BOD test. Further, the test is relatively easy, precise, and is unaffected by interferences as in the BOD test. The intrinsic limitation of the test lies in its inability to differentiate between the biologically oxidizable and biologically inert material and to find out the system rate constant of aerobic biological stabilization.

5.8.6. Total coliform

The coliform group consists of several genera of bacteria belonging to the family Enterobacteriaceae. The historical definition of this group has been based on the method used for detection (lactose fermentation) rather than on the tenets of systematic bacteriology. Accordingly, when the fermentation technique is used, this group is defined as all facultative anaerobic, gram-negative, non-spore-forming, rod-shaped bacteria that ferment lactose with gas and acid formation within 48 h at 35°C.

The standard test for the coliform group may be carried out either by the multiple-tube fermentation technique or presence-absence procedure (through the presumptive-confirmed phases or completed test) described herein, by the membrane filter (MF) technique or by the enzymatic substrate coliform test. Each technique is applicable within the limitations specified and with due consideration of the purpose of the examination.

5.8.7. Ammonia (NH3)

Nitrogen, as ammonia, is a critical nutrient in biological wastewater treatment. It is utilized by bacteria to make proteins, including enzymes needed to break down food or BOD as well as in making energy. In both aerated stabilization basins and activated sludge wastewater systems, insufficient nutrient availability will lead to poor biochemical oxygen demand (BOD) removal due to the inability of the bacteria to divide and create more workers.

The two major factors that influence selection of the method to determine ammonia are concentration and presence of interferences. In general, direct manual determination of low concentrations of ammonia are confined to drinking waters, clean surface or groundwater, and good-quality nitrified wastewater effluent. In other instances, and where interferences are present or greater precision is necessary, a preliminary distillation step is required.

5.8.8. Total Nitrogen (TN)

TN is sometimes regulated as an effluent parameter for municipal and industrial wastewater treatment plants, but it is more common for limits to be placed on an individual nitrogen form, such as ammonia. Treatment plants that have a TN limit will usually need to nitrify and denitrify in order to achieve the TN limit. Because nitrogen in wastewater can be found in four major forms (excluding trace amounts of nitrogen gas), each major form is generally analyzed as a separate component, with Total Nitrogen calculated from the sum of the four forms.

5.8.9. Total Phosphorus (TP)

Phosphorus is an essential nutrient of plant, animal and human. The parameter total phosphorus (TP) defines the sum of all phosphorus compounds that occur in various forms.

Phosphorus (P) is a nutrient that is vital to human, animal, and plant growth. It's one of the most common substances found in nature. It's found in our water, our food, and our bodies. High levels of phosphorus in nature can create algal blooms causing eutrophication or the premature "aging" of a water body. This process decreases sunlight and oxygen levels (hypoxia) thus affecting fish and other aquatic life.

5.8.9.1. Oil and Grease

Oil and grease are any material recovered as a substance soluble in petroleum ether, hexane or nhexane. It includes other materials extracted by the solvent from an acidified sample such as Sulphur compounds, certain organic dyes and chlorophyll.

Oil and grease are defined by the method used for their determination. The oil and grease content of domestic industrial wastes and of sludges, is an important consideration in the handling and treatment of these materials for ultimate disposal. When treated effluents are discharged in water body, it leads to environmental degradation. Hydrocarbons, esters, oils, fats, waxes and high molecular weight fatty acids are the major materials dissolved by hexane.

6. MAINTENANCE AND REPAIR OF CIVIL AND MECHANICAL STRUCTURES

6.1. Inspection and Assessment of Civil Components:

Wastewater treatment plants, given their nature of operation, are prone to wear and tear, especially in their civil components. The inspection process involves a systematic examination of these structures, which might range from containment basins and tanks to various other structural elements. Advanced tools, such as ultrasonic testing devices, play a crucial role in identifying internal inconsistencies, damages, or degradations which might not be evident on the surface.

Once the inspection is completed, the assessment phase takes precedence. Here, engineers and experts analyze the findings to determine the severity and implications of any identified damage. Not only does this process help in understanding the immediate repair needs, but it also aids in predicting potential future vulnerabilities, ensuring proactive interventions.

6.2. Regular Maintenance Activities:

To ensure longevity and consistent performance of a wastewater treatment plant, regular maintenance of its civil components is indispensable. This typically involves the routine cleaning of basins and tanks to prevent sediment accumulation which can impede operations or cause undue stress on structures.

Moreover, minor infractions such as small cracks or leaks are identified and promptly sealed, preventing them from evolving into major issues. Protective measures also come into play, with structures, especially those that are exposed to particularly aggressive wastewater conditions, being treated with protective coatings or paints. These coatings are not just about preventing corrosion but also about safeguarding structures from environmental adversities. Further, for structures that are integrated with instruments, periodic calibration becomes necessary to ensure accurate readings and optimal operation.

6.3. Repair Procedures for Concrete Structures:

Concrete, while being a robust material, is susceptible to damage, especially in the aggressive environment of wastewater treatment facilities.

When cracks manifest in concrete structures, depending on their extent, they might be sealed using specialized techniques like epoxy injection, or for more significant cracks, the use of concrete patches becomes necessary.

Beyond cracks, surface damages such as spalling (where fragments of material are dislodged from the surface) can arise. In such cases, treatments may involve the application of overlays to restore the structural and functional integrity. At times, the very steel reinforcing the concrete corrodes, prompting not just a surface repair but also an intervention at the reinforcement level. Once the repair is executed, a final protective layer, often a chemically resistant coating, is applied to the concrete. This not only reinforces the structure but also ensures longevity by preventing future damage.

6.3.1. Controlling erosion

Erosion challenges are often more pronounced on the downwind side of the pond, exacerbated by increased wave actions due to wind sweeping across the pond's surface. Consequently, regular inspections of certain areas become crucial, including around control structures, corners, sections where the vegetative cover on the dikes is sparse, and zones where dikes weren't adequately compressed during construction.

Erosion significantly diminishes the projected lifespan of a pond system. The adverse effects of erosion include:

- Removal of the liner's protective cover or potentially the liner itself.

- Formation of areas on the dikes that are hard to maintain.
- Augmentation in the likelihood of muskrat habitation, leading to dike damage.

One of the most effective means to manage erosion is the use of riprap material. For new pond systems, riprap or other equivalent erosion control methods are mandated for all internal dike slopes. Before introducing riprap to pre-existing pond systems, it's essential to ascertain the seal's integrity. The riprap material should extend from the dike's base to at least 0.3 meters above the maximum water mark. Modern design guidelines advocate for the riprap to cover up to the dike's summit.

6.4. Repair Procedures for Piping and Channels:

Pipes and channels serve as the lifelines of wastewater treatment plants, directing flow and ensuring the seamless operation of various treatment processes. Over time, these components, due to constant exposure to wastewater, can manifest leaks or even breakages. Advanced techniques, such as acoustic or electromagnetic sensing, can pinpoint even minor leaks, especially in buried pipelines. Addressing these leaks might involve methods ranging from the application of clamps to more extensive pipe relining or even sectional replacements for substantial damages. Channels, especially when they suffer from surface erosion or degradation due to chemical exposures, might necessitate resurfacing interventions.

Furthermore, the joints or sealants binding pipe sections or channels can, over time, fail or degrade. Repairing or replacing these is crucial to ensure a fully integrated and leak-proof system, ensuring the efficacy of the wastewater treatment process.

6.5. Control structure

Control structures are pivotal in managing water levels. It's imperative for an operator to ensure their consistent and correct functionality. Common issues with these structures include corrosion and leaks.

To mitigate the corrosion issue, it's recommended to regularly lubricate gates and valves. This can be achieved by frequently operating the gates and valves to ensure they remain mobile. An alternative method to counteract corrosion is enhancing ventilation, which can be accomplished by swapping out solid manhole covers with gate covers.

Fixing leaks in these structures can be challenging. An operator might resort to using gasket materials, grout, or sewer plugs to address the leakage. Nonetheless, for a more lasting solution, it's often necessary to replace the affected gates, slides, or telescoping valves.

7. MANAGEMENT OF THE SLUDGE FROM WSP

7.1. Removal of Sludge from Stabilization Ponds

As in all biological wastewater treatment processes, there is also production of sludge in stabilization ponds. This sludge is associated with the solids present in the raw sewage and, mainly, with the biomass developed in the biological treatment itself. The various chapters that cover stabilization pond variants in this book present values for the estimated volumetric sludge production (expressed in m^3/inhab.year or in cm/year). This chapter presents additional details about the characteristics of the sludge and, mainly, about the management of the sludge from stabilization ponds.

One of the main advantages of the *facultative* ponds is the possibility to accumulate sludge on the bottom of the pond, during the whole operational period, with no need for its removal. However, in the most *compact* ponds (anaerobic ponds, facultative aerated lagoons and sedimentation ponds), the occupation of the useful volume of the pond with the accumulated sludge is more significant, requiring an appropriate management, including removal, occasional processing and final disposal.

The characteristics of the sludge accumulated in the stabilization ponds vary ac- cording to its retention time in the pond, which usually amounts from some to many years. In this period, the sludge undergoes *thickening* and *anaerobic digestion*, which are reflected on the high contents of total solids (TS) and on the low volatile solids / total solids ratio (VS/TS).

The sludge removed from primary ponds usually presents high contents of total solids, frequently higher than 15%. Because of thickening, the solids concentration varies along the sludge layer, with higher values in the lower parts. Sludges from shallow polishing ponds accumulated over short time periods (one year or less) have average solids concentrations of approximately 4 to 6% (Brito et al, 1999; von Sperling et al, 2002b).

The sludge from ponds operating for several years is usually well digested, with VS/TS ratios lower than 50%.

In terms of nutrients (nitrogen, phosphorus and potassium), the data obtained from an anaerobic pond and from a primary facultative pond (Gonc¸alves, 1999) suggest nutrient contents lower than those obtained from other wastewater treat- ment processes. The average values obtained were: TKN: 2.0% of the TS; P: 0.2% of the TS; K: 0.04% of the TS.

Regarding coliforms, the contents in the sludge range between 10^2 and 10^4 FC/gTS, and their decay takes place during the accumulation period in the pond.

Helminth eggs are found in large quantities in pond sludge, since the main egg removal mechanism from the liquid phase is sedimentation. The figures vary substantially from one wastewater treatment plant to another, in view of the variable counting in the raw sewage in each location. A long sludge digestion period in the pond seems to contribute to a reduced viability of the eggs. However, it is important to highlight that the sludge from ponds, even after several years, still contains viable eggs, what must be taken into account in their management. Data on the sludge from the anaerobic pond mentioned above, operating for several years, are associated with a percentage of viability between 1 and 10%, while the sludge from the polishing ponds, after operation periods of only six months and one year, presented much higher percentages of viability, between 60 and 90%. The helminth species prevailing in the referred to ponds was *Ascaris lumbricoides*, ranging from 50 to 99% of the total counting of eggs found. On worldwide terms, the most prevailing helminth species is *Ascaris lumbricoides*, but of course the counting and the percentage distribution will vary from place to place.

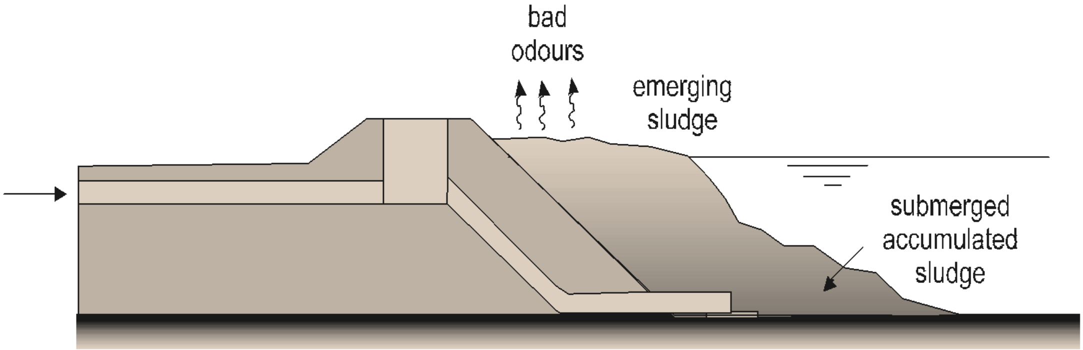


Figure 7-1: Non-homogeneous spatial distribution of the sludge, with sludge rising to the surface and possible release of malodorous compounds

The thickness and the characteristics of the sludge layer vary inside the ponds, depending on their geometry and on the positioning of the inlet and outlet structures. Different profile patterns were observed by Gonçalves (1999), but the most frequent one, mainly in primary ponds and in elongated (baffled) ponds, is that of a higher sludge layer close to the inlet. The greatest concern occurs when the sludge layer rises up to and over the water surface, allowing the release of malodorous compounds. This situation happens more frequently in ponds without previous grit removal and in anaerobic ponds. In case the sludge is not removed, at least the inclusion of a grit chamber and the redistribution of the emerging sludge layer and of the pond inlets should be performed.

The removal of sludge is likely to be a compulsory task of a significant scale in the operation of many ponds. However, there is still no widely accepted engineering solution for that. The removal needs to be well planned, since the technique used can change the characteristics of the sludge (increase the water content), and hinder its final disposal.

Figure 7-2: WSP

7.1.1. How do you know when to desludge?

- Recommended that after every two years (depending on the effluent received) measure the sludge depth.
- The simplest way of doing this is so called the **"white towel method".**
- A white cloth is wrapped around an approximately 2 m long pole attached together with tape measure.
- Try to get to the centre (maximum depth) of the pond where most sludge is likely to accumulate. Ideally, this is a difficult exercise in most waste stabilization ponds system, however, some ponds have an extended inlet channel that can be used to stand or lie on. The exercise can be done at the accessible position to get some indication.
- The depth of the sludge is measured by lowering the pole vertically into the pond until it reaches the bottom, it is then slowly withdrawn.
- Sludge particles are trapped on the toweling material so that the sludge is clearly visible as shown in the following picture.
- The sludge depth and full depth of the liquid can be read from the marks left on the white towel and stick using the attached tape measure.

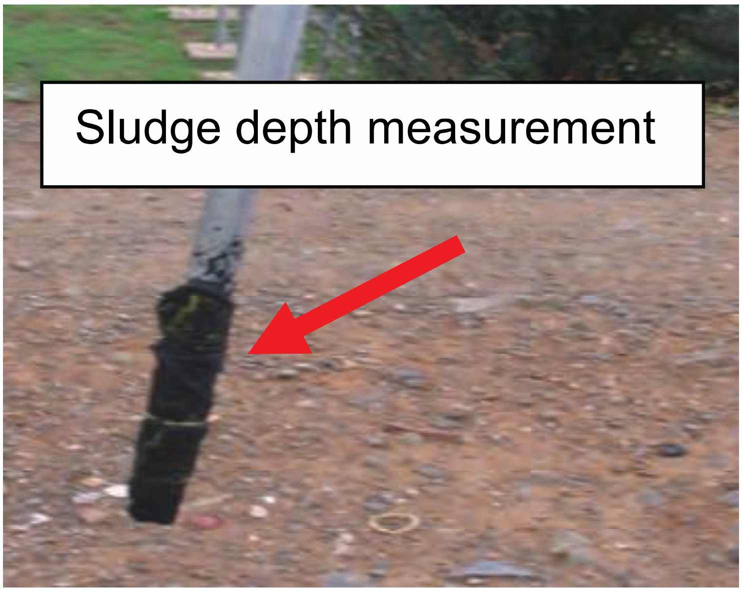


Figure 7-3: Sludge depth measurement

- Anaerobic ponds require desludging when they are one third full of sludge (by volume).
- Maturation ponds are not expected to contain significant sludge that could require desludging because settled solids are removed within anaerobic and facultative ponds.

7.1.2. Information on the sludge volume to be removed

The planning of the sludge removal from a pond has the purpose of minimizing costs, anticipating solutions to occasional problems, and reducing impacts related to the sludge removal and disposal. The following stages are essential in the cleaning operation:

- Determination of the pond geometry based on the design or on a topographic survey.
- Accomplishment of the pond bathymetry, defining bathymetric sections, liquid height of the pond, and depth of the sludge layer.

- Physical–chemical and microbiological characterization of the sludge.
- Definition of the technique to be adopted in the removal of the sludge and, if necessary, in the sludge dewatering and transportation.
- Definition of the adequate final destination of the sludge, considering the lowest possible environmental impacts.

Certainly, stages 1, 2, and 3 are pre-requisites for the implementation of stage 4, which defines the technique to remove the sludge from the pond. Although there is no consensus on the technique, its selection has a direct impact on the water content of the sludge and, therefore, on the sludge volume to be disposed of later on.

7.1.3. Techniques for Sludge Removal

Generally the procedure is adopted as given below:

- Sludge could be drained or sucked from the bottom using a honey sucker (most appropriate for single inlet waste stabilization pond systems).
- For multiple inlet/receiving ponds divert the influent to one pond (that is not being desludged). Drain the pond effluent from the surface to avoid sucking the bottom sludge.
- Once you reach the sludge level stop draining.
- Let the sludge dry at the bottom of the pond and remove using spades and excavator.
- Removed sludge should be disposed at an appropriate landfill sites indicated by the supervisor.
- Put the clean pond back into operation and clean the second pond.

7.1.3.1. Main techniques for sludge removal

The main pond sludge removal techniques can be classified as follows:

- Mechanised or non Mechanised
- with interruption or no interruption of the pond operation

This second classification was adopted in the following description, due to the importance of the decision of whether to maintain the pond in operation or not.

For the cases in which the sludge should be submitted to dewatering af- ter removal, the following alternatives can be considered: natural drying in the pond itself, use of drying beds, sludge lagoons, or even the use of mechanical equipment.

In locations with a large number of ponds in the surroundings, the use of a mobile dewatering unit (e.g. with centrifuges) could be taken into consideration.

7.1.3.2. Sludge removal with temporary interruption of the pond operation

The temporary deactivation of a pond can be a simple operational measure, if the primary pond stage has been designed in modules, and if there is an idle treatment capacity. However, if this stage consists of a single pond, or if the nominal design load has been already reached, the temporary deactivation may put in risk the stability of the subsequent treatment stage.

Another important aspect is related to emptying the pond. This operation, necessary for drying the sludge in the pond itself, requires previous planning and consent from the environmental agency. In case of very fast emptying, mainly in

anaerobic ponds, the impact of the anaerobic effluent on the receiving body can exceed its self-purification capacity. Fish death, unpleasant odours and protests by the population may arise as a consequence.

4.1.3.1. Sludge removal with the pond in operation

a) Removal by hydraulic sludge discharge pipe

The hydraulic sludge discharge pipe (bottom drain) is the device more frequently included in the design of anaerobic or aerated stabilization ponds. Nevertheless, it is a solution highly criticised by operators.

There are several reports on clogging and loss of function of this device during the operation of the pond. The problem occurs in view of the evolution of solids contents in the sludge over the years, making its consistency change from liquid to pasty. Should the sludge be discarded with a higher frequency (<5 years), which would prevent its thickening at levels higher than 7% on the bottom of the pond, this device could be useful in small sewage treatment plants. For Victoretti (1975), sludge discharge devices are unnecessary, because the ponds operate for long periods with no need of sludge removal. According to the author, the units should be designed to be deactivated for drainage and removal of the sludge.

In case this technique of pond sludge removal is adopted, pipe diameters equal to or larger than 200 mm are recommended (Metcalf and Eddy, 1991).

b) Removal by septic tank cleaning truck

Septic tank cleaning or similar trucks are provided with a vacuum suction system with a flexible pipe that removes the sludge and conveys it to the sludge storage compartment in the trucks themselves.

Figure 7-4: Suction Machines or Septic Tank Cleaners

The disadvantage of this solution is that it removes the sludge with a high water level, once pumping requires the dilution of the sludge layers already in an advanced thickening stage. The result can be the need of many trips to transport the sludge from the sewage treatment plant to the disposal site. However, its great advantage is that it removes and transports the sludge in the same operation. The equipment can also be easily found and rented in medium- and large-sized cities.

7.1.3.3. Suction Dredging

Suction dredgers are specifically designed equipment that can navigate the surface of stabilization ponds and remove the sludge accumulated at the bottom through a powerful vacuum system.

The apparatus consists of a floating unit on which a pump and suction head are mounted. As the dredger moves across the pond, the suction head, submerged at a controlled depth, vacuums up the sludge. The efficiency of this method is significant as it doesn't necessitate the pond to be emptied. The dredger can work in sections, ensuring minimal disruption to the pond's function. The slurry of water and sludge collected by the dredger is then directed to dewatering facilities for further processing.

7.1.3.4. Mechanical Scraping

Mechanical scrapers operate by traversing the bottom of the pond, pushing or gathering the sludge towards a designated collection point or pit. Once accumulated, the sludge can be pumped or scooped out for further treatment. Automated scrapers are mounted on rails or guided systems and can be programmed to operate at specific intervals, ensuring consistent sludge management. These systems are especially suitable for larger stabilization ponds where manual removal would be excessively labor-intensive.

When the pond cannot be deactivated for a very long period of time, the sludge is partially dried in the air, mechanically scraped, and then pumped. This technique requires the aid of a tractor or another device to convey the sludge still in the liquid state to a lower point from where it will be pumped.

Figure 7-5: Use of pumps

The use of positive displacement pumps (piston, diaphragm, rotating lobes, high-pressure piston, etc.) is recommended due to their capacity to move the sludge mass. Torque pumps (centrifuges) can be used, although they require dilution of the highly concentrated sludge, which results in an increased volume of sludge removed.

7.1.3.5. Mechanical removal (by tractors)

As in the previous technique, the sludge is submitted to drying in the pond and removed soon after. In view of the higher yield of the machines in the sludge removal, the pond can start to work again more quickly than in case of manual removal. However, for tractors or shovels to gain access to the bottom of the pond, the soil support capacity should be previously verified, so that neither the pond bottom sealing nor the stability of the slopes are affected.

Figure 7-6: Mechanical Removal

The ease of access of the machines into the pond should be evaluated, considering the option of partial rupture of the slopes for further reconstruction. There have been cases of tractors stuck in the sludge in ponds, for which reason it is recommended that the bottom of the pond should not be accessed while the sludge presents a pasty consistency (20% < TS < 30%).

7.1.3.6. Manual Removal

For smaller ponds or in settings where specialized machinery might not be feasible, manual removal becomes an option. The process begins by draining or partially emptying the pond to expose the sludge. Workers, equipped with shovels, rakes, and other tools, then manually collect the sludge. Given its labor-intensive nature, this method allows for thorough cleaning and offers an excellent opportunity to inspect the pond's liner, sides, and other structural elements for any potential damages or wear.

In this case, the sludge is submitted to drying inside the pond itself, until it is consistent enough to be removed by spades and wheelbarrows (TS>30%).

The disadvantage of this technique is that it requires a long drying period. Considering the period of time necessary to empty the pond, the drying period, and the period for the manual removal of the sludge, the pond will certainly remain deactivated for more than 3 months.

However, the sludge volume to be removed under these conditions is much lower than the volume existent prior to the drying. Another positive aspect is the possible complementary disinfection of the sludge by sunlight-induced pasteurisation. This can be a feasible solution for small sewage treatment plants (<5000 inhabitants).

7.1.3.7. Hydraulic Removal

This method uses the force of water to move the sludge. Water is introduced at one end of the pond, creating a flow that pushes the sludge towards the opposite end where it gets collected in a sump or pit. The method requires a careful control of water velocity to ensure effective sludge movement without causing resuspension of solids.

7.1.3.8. Robotic Sludge Removal

Emerging technologies have introduced robotic systems designed for sludge removal. These robots, equipped with sensors, can navigate the pond floor, vacuuming or collecting sludge. Given their precision, they can be programmed to remove sludge layer by layer, ensuring thorough cleaning. Their use minimizes human intervention, making the process more efficient and less labor-intensive.

The choice of sludge removal technique often depends on the size of the pond, the amount and type of sludge accumulated, available resources, and budgetary constraints. Regardless of the method chosen, regular removal and management of sludge are critical to maintain the efficiency and capacity of stabilization ponds.

Advantages and disadvantages of the sludge removal techniques from stabilization ponds

Table 7-1: Advantages and disadvantages of the sludge removal techniques from stabilization ponds

Sludge removal techniques used with deactivation of the pond		
Technology	Advantages	Disadvantages
Manual removal	• Sludge humidity is removed in the pond itself • Cleaning of the pond is done in a controlled way • Sludge with high TS contents reduces transport costs • Almost complete removal of the sludge	• The pond is deactivated for a long period of time • Employees have direct contact with the sludge
Mechanical removal (by tractors)	• Sludge humidity is removed in place • Cleaning of the pond is done in a controlled way • Sludge with high TS contents reduces transport costs • Higher yield than that of manual sludge removal • Almost complete removal of the sludge	• The pond is deactivated for a long period of time • Possible demolition of part of the slope for machine access • The bottom of the pond may be damaged, requiring repairs • Tractor may get stuck in the sludge
Mechanised scraping and pumping	• Shorter sludge drying time in the pond • Almost complete removal of the sludge	• Removal of sludge with a high water content • Requires tractor access in the pond
Sludge removal techniques with the pond in operation		
Technology	Advantages	Disadvantages
Vacuum system from a septic tank cleaning truck	• Operational simplicity • The equipment is easily available • The sludge is removed and transported in the same operation	• Sludge removal with higher frequency – requires low TS contents • Removal of sludge with a high water content due to the mixing with the liquid during the operation • Requires natural or mechanical dewatering of the sludge removed
Hydraulic discharge pipe	• Operational simplicity • Low cost	• Discharge device gets blocked • Sludge discharge with higher frequency – requires low TS contents • Requires natural or mechanical dewatering of the sludge removed • Difficult control of the discharge operation

Sludge removal techniques with the pond in operation		
Technology	Advantages	Disadvantages
Dredging	• Removes the sludge almost completely • Sludge removed with high concentration of solids • Cleaning can be done at a lower frequency	• Need of natural or mechanical dewatering of the sludge removed • Difficult control of the sludge removal operation • Cost of the equipment
Pumping from raft	• Operational simplicity • The equipment is easily available	• Sludge removal with higher frequency – requires low TS contents • Requires natural or mechanical dewatering of the sludge removed • Difficult control of the sludge removal operation
Robotic system	• Removes the sludge almost completely • Sludge with high TS contents reduces transport costs • Allows pond cleaning at lower frequency	• Cost of the equipment • Little availability of the equipment in developing countries

Comparison of the main factors for selection of the sludge removal technique in stabilization ponds

Table 7-2: Comparison of the main factors for selection of the sludge removal technique in stabilization ponds

Technique	Performance	Ease of operation	Execution time	Sludge volume	Cost
Manual removal	* * * *	* *	* * * *	*	* *
Mechanical removal (by tractors)	* * * *	* * *	* * *	*	* *
Mechanised scraping and pumping	* * *	* *	* * *	* *	* *
Vacuum system from a septic tank cleaning truck	*	* * *	* *	* * * *	* * *
Hydraulic discharge pipe	*	* * * *	* *	* * *	*
Dredging	* * *	* *	* *	* * *	* * *
Pumping from raft	* *	* *	* *	* * *	* *
Robotic system	* * * *	*	* *	* *	* * * *

Scale: * * * * Larger →→→ * Smaller

The comparison is just for an initial analysis, since the specific conditions of each stabilization pond can change completely the applicability of the techniques at issue.

7.2. Sludge Drying Beds/Lagoons:

The management of the removed sludge is a critical aspect of wastewater treatment. This is where sludge drying beds and lagoons play a pivotal role. Essentially, these are large, open areas where the sludge is uniformly spread to allow natural drying. The design of these beds is crucial. They often consist of a layer of sand and gravel, underlain by a network of drainage pipes. As the sludge dries under the sun, the liquid part percolates through the sand and gravel layers, getting collected in the pipes below.

Figure 7-7: Sludge Drying Beds

Sludge drying bed (SDB) is the most widely used method for sludge dewatering. Sludge drying involves natural ways of drying to mechanical ways of removing water content. SDB is generally used for small and medium sized communities (TCHOBANOGLOUS et al. 2003). The selection of the technology will depend upon land availability, climatic factors, the quantity and composition of the sludge. The construction of this is usually undertaken with civil structure.

7.2.1. Design and Construction Principle

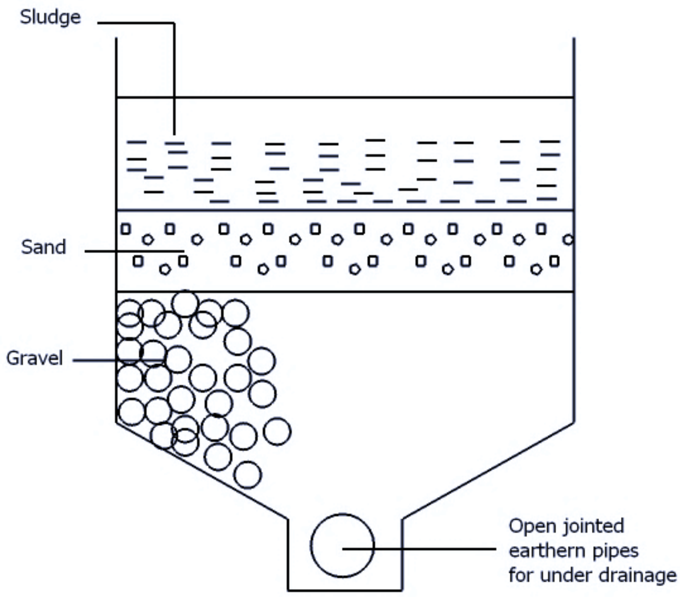


Figure 7-8: Design of Sludge Drying Beds

The typical conventional SDB has dimensions of 6 m width, 6 - 30 m length, with sand layer ranging from 230 – 300 mm depth. The sand should have a uniformity coefficient of not over 4.0 and effective size of 0.3 to 0.75 mm. The piping to the sludge drying beds should be designed for velocity of at-least 0.75 m/s (TCHOBANOGLOUS et al. 2003). The sludge is placed on the bed in 20–30 cm layers and allowed to dry. Sludge cake removal is manual by shovelling into wheel-barrows, trucks, scraper, or front-end loader. The drying period is 10–15 days, and the moisture content of the cake is 60 – 70%. Sludge loading rate is 100–300 kg dry solids/ m^2 /year for uncovered beds (AL-MALACK et al. 2002).

Under unfavorable conditions, the land requirement for an aerobically digested sludge can be significant, ranging from 0.1 to 0.25 m^2/capita.

The following are the requirements for preparing sludge drying beds:

Underdrains: Underdrains are built of open-jointed vitrified clay pipe or tiles with a minimum diameter of 10 cm. Pipes should not be laid further than 6 meters apart. It should be arranged for the drained water to be returned to the primary sedimentation tank.

Gravel: Gravel is used to cover the drainage system under the surface. Gradated gravel is placed in layers up to 30 cm around the under drains, with a minimum of 15 cm above the drains. The top 3 cm of gravel should be 3 to 6 mm thick.

Sand: Sand is employed, with an effective size of 0.5 to 0.75 mm and a uniformity coefficient of no more than 4. The sand depth can range from 20 to 30 centimeters.

transforms from a potential environmental problem to a manageable, and sometimes useful, resource.

7.3. Sludge disposal

Figure 7-9: Sludge from WWTP

Sludge, the byproduct of wastewater treatment, is laden with various contaminants ranging from heavy metals to organic pollutants. Ensuring its proper disposal is a cornerstone of environmental protection. If disposed of carelessly, these contaminants have the potential to leach into the soil, making their way into groundwater or surface water systems, which can lead to significant environmental degradation. Beyond containment, there's an opportunity in sludge. Processed appropriately, what might be seen as waste can be transformed.

Following are some techniques of sludge disposal widely used across the world

7.3.1. Land Application

Table 7-3: Types of land use

Type of use	Comment
Sanitary landfill	Disposal of the sludges in ditches or trenches, with compaction and covering with soil, until they are totally filled, after which they are sealed. The sewage sludge can be disposed of in dedicated landfills or co-disposed with urban solid wastes. Disposal without beneficial uses.
Landfarming	Land disposal process, in which the organic substrate is biologically degraded in the upper layer of the soil and the inorganic fraction is transformed or fixed into this layer. Disposal without beneficial uses.
Land reclamation	Disposal of sludge in areas that have been drastically altered, such as mining areas, where the soil does not offer conditions for development and fixation of vegetation, as a result of the lack of organic matter and nutrients.
Agricultural reuse	Disposal of the sludge in agricultural soils, in association with the development of crops. Beneficial use of the sludge (which, in this case, is named as a biosolid).

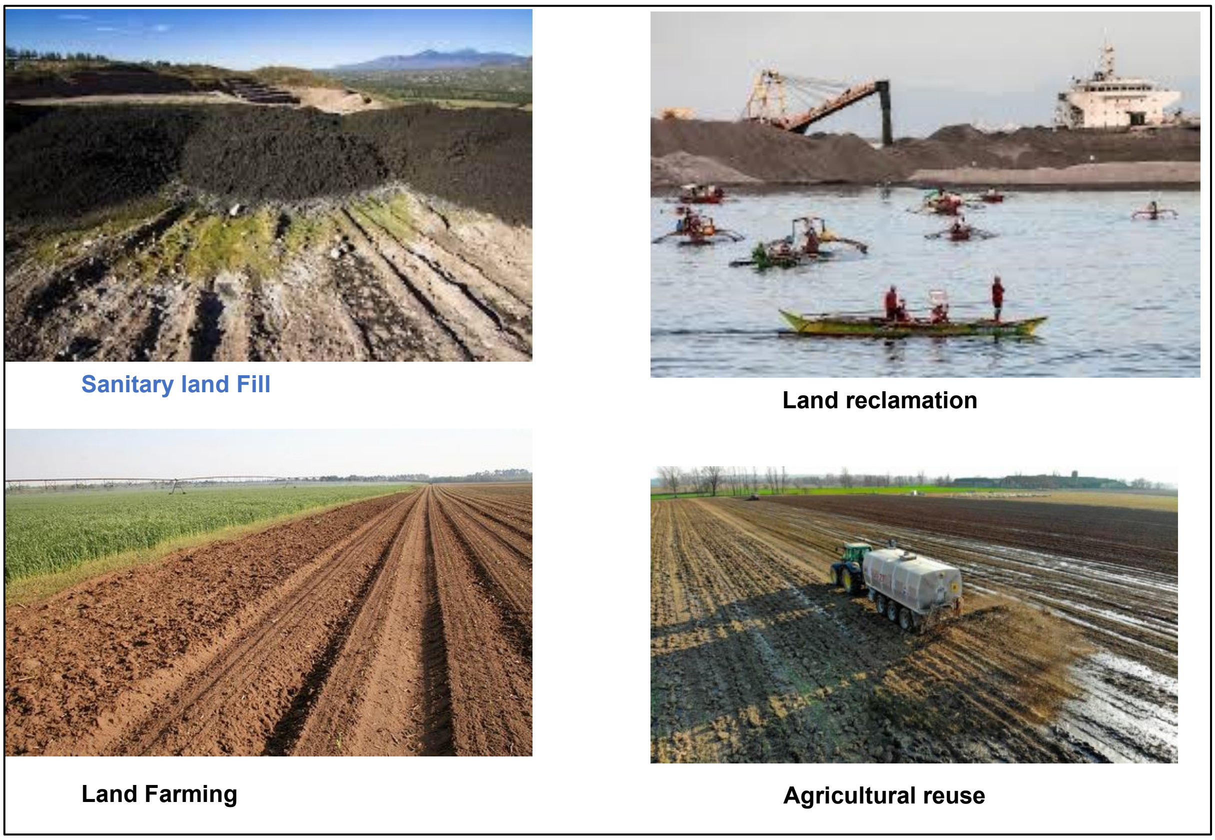


Figure 7-10: Sludge land applications

7.3.2. Advantages and disadvantages of the main sludge disposal alternatives

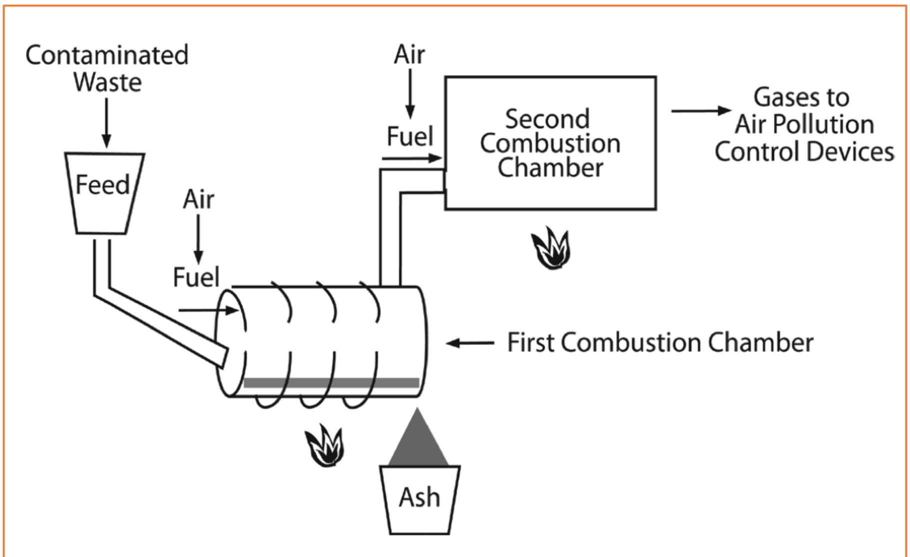
Table 7-4: Advantages and disadvantages of the main sludge disposal alternatives

Type of use	Advantages	Disadvantage
Sanitary landfill	Low cost	Requirement of large areas Problems with locations near urban centres Requirement of special soil characteristics Gas and leachate production Difficulty in reintegrating the area after decommissioning

Type of use	Advantages	Disadvantage
Landfarming	Low cost Disposal of large volume per unit area	Accumulation of metals and hardly decaying Possible groundwater contamination Odour release and vector attraction Difficulty in reintegrating the area after decommissioning
Land reclamation	High application rate Positive results for the recovery of the soil and flora	Odours Composition and use limitations Contamination of the groundwater, fauna and flora
Agricultural reuse	Large area availability Positive effects for the soil Long term solution Potential as a fertiliser Positive outcome for the crops	Limitations regarding composition and application rates Contamination of the soil by metals Food contamination with toxic elements and pathogenic organisms Odours

7.3.3. Incineration

Sludge which is highly contaminated with heavy metals or other undesirable pollutants is not allowed to be used in agriculture or disposed in landfill. In this case, incineration could be chosen as a feasible final method of disposal.



How an incinerator converts waste into ash and gases.

Figure 7-11: How an Incinerator works?

Sludge, either alone or in combination with other waste, is incinerated at an optimal furnace temperature of 800 to 900°C. To reduce the fuel required for combustion, sludge needs to be dewatered to around 25% of solids content at least. The calorific value of sludge is the main determining factor in whether additional fuel is needed during the process. The residual ash from the process is a stable and inorganic substance which can be recycled in construction materials or disposed in landfill.

This process helps to reduce sludge volume by up to 90% and sludge mass by up to 60%. It completely destroys pathogens, eliminates leachate and minimizes odors due to a fully enclosed and high temperature system. Low sensitivity to sludge composition is also among the advantages of incineration.

On the other hand, incineration facilities consume a great amount of fuel, and release the greenhouse gas carbon dioxide into the atmosphere. The fumes produced require a very specific treatment before being released into the atmosphere which makes this technology rather costly.

Incineration destroys organic substances and pathogenic organisms through combustion obtained in the presence of excess oxygen.

Incineration is a Thermal decomposition process by oxidation, in which the volatile solids of the sludge are burnt in the presence of oxygen and are converted into carbon dioxide and water. The fixed solids are transformed into ashes. Disposal without beneficial uses.

- Depending on the contaminants present, the target temperature may range from 870 C^0 to 1370 C^o.
- The residual ashes volume is usually less than 4% of the dewatered sludge volume fed to incineration.
- EPA requires that an incinerator can destroy and remove at least 99.99 percent of each harmful chemical in the waste it processes.

8. DISPOSAL, REUSE OF EFFLUENT FOR IRRIGATION

8.1. Wastewater reuse in Agriculture

Wastewater is increasingly used for agriculture in both developing and industrialized countries, and the principal driving forces are:

- increasing water scarcity and stress, and degradation of freshwater resources resulting from improper disposal of wastewater;
- population increase and related increased demand for food and fiber;
- a growing recognition of the resource value of wastewater and the nutrients it contains;
- the Millennium Development Goals (MDGs), especially the goals for ensuring environmental sustainability and eliminating poverty and hunger.

It is estimated that, within the next 50 years, more than 40% of the world’s population will live in countries facing water stress or water scarcity. Growing competition between the agricultural and urban uses of high-quality freshwater supplies, particularly in arid, semi-arid and densely populated regions, will increase the pressure on this ever-scarcer resource.

The United Nations Population Division expects most population growth to occur in urban and peri urban areas in developing countries. Population growth increases both the demand for fresh water and the number of wastes that are discharged into the environment, thus leading to more pollution of clean water sources.

Figure 8-1: Irrigation using wastewater

Wastewater is often a reliable year-round source of water, and it contains the nutrients necessary for plant growth. The value of wastewater has long been recognized by farmers worldwide. The use of wastewater in agriculture is a form of nutrient and water recycling, and this often reduces downstream environmental impacts on soil and water resources.

The United Nations General Assembly adopted the MDGs on 8 September 2000. The MDGs most directly related to the use of wastewater in agriculture are "Goal 1: Eliminate extreme poverty and hunger" and "Goal 7: Ensure environmental sustainability." The use of wastewater in agriculture can help communities to grow more food and conserve precious water and nutrient resources.

8.1.1. Assessment of health risk

Three types of evaluations are used to assess risk: microbial and chemical laboratory analysis, epidemiological studies and quantitative microbial (and chemical) risk assessment.

Wastewater contains a variety of different pathogens, many of which are capable of survival in the environment (in the wastewater, on the crops or in the soil) long enough to be transmitted to humans. In places where wastewater is used without adequate treatment, the greatest health risks are usually associated with intestinal helminths.

Table 8-1 presents a summary of the quantitative microbial risk assessment (QMRA) evidence for transmission of rotavirus infection due to different exposures. The risks for rotavirus transmission were always estimated to be higher than the risks associated with *Campylobacter* or *Cryptosporidium* infections.

Summary of health risks associated with the use of wastewater for irrigation

Table 8-1: Summary of health risks associated with the use of wastewater for irrigation

Group exposed	Health threats		
	Helminths	**Bacteria/viruses**	**Protozoa**
Consumers	Significant risks of helminth infection for both adults and children with untreated wastewater	Cholera, typhoid and shigellosis outbreaks reported from use of untreated wastewater; seropositive responses for *Helicobacter pylori* (untreated); increase in non-specific diarrhoea when water quality exceeds 10^4 thermotolerant coliforms per 100 ml	Evidence of parasitic protozoa found on wastewater-irrigated vegetable surfaces, but no direct evidence of disease transmission
Farm workers and their families	Significant risks of helminth infection for both adults and children in contact with untreated wastewater; increased risk of hookworm infection to workers who do not wear shoes; risks for helminth infection remain, especially for children, even when wastewater is treated to <1 helminth egg per litre; adults are not at increased risk at this helminth concentration	Increased risk of diarrhoeal disease in young children with wastewater contact if water quality exceeds 10^4 thermotolerant coliforms per 100 ml; elevated risk of *Salmonella* infection in children exposed to untreated wastewater; elevated seroresponse to norovirus in adults exposed to partially treated wastewater	Risk of *Giardia intestinalis* infection reported to be insignificant for contact with both untreated and treated wastewater; another study in Pakistan estimated a threefold increase in risk of *Giardia* infection for farmers using raw wastewater compared with irrigation with fresh water; increased risk of amoebiasis observed from contact with untreated wastewater
Nearby communities	Transmission of helminth infections not studied for sprinkler irrigation, but same as above for flood or furrow irrigation with heavy contact	Sprinkler irrigation with 68 poor water quality (10 –10 total coliforms/100 ml) and high aerosol exposure associated with increased rates of infection; use of partially treated water 45(10 –10 thermotolerant coliforms/100 ml or less) in sprinkler irrigation is not associated with increased viral infection rates	No data for transmission of protozoan infections during sprinkler irrigation with wastewater

8.1.2. Health-based targets for wastewater use in agriculture

Table 8-2: Health-Based Targets for Wastewater Use in Agriculture

Exposure scenario	Health-based target (DALY per person per year)	Log10 pathogen a reduction needed	Number of helminth eggs per litre
Unrestricted irrigation	$\leq 10^{-6}$ [a]		
Lettuce		6	≤[1b,c]
Onion		7	≤[1b,c]
Restricted irrigation	$\leq 10^{-6}$ [a]		

Highly mechanized		3	$\leq 1^{b,c}$
Labour intensive		4	$\leq 1^{b,c}$
Localized (drip) irrigation	$\leq 10^{-6}$ [a]		
High-growing crops		2	No recommendation[d]
Low-growing crops		4	$\leq 1^{b,c}$

- [a] Rotavirus reduction. The health-based target can be achieved, for unrestricted and localized irrigation, by a 6–7 log unit pathogen reduction (obtained by a combination of wastewater treatment and other health protection measures); for restricted irrigation, it is achieved by a 2–3 log unit pathogen reduction.
- [b] When children under 15 are exposed, additional health protection measures should be used (e.g. treatment to ≤0.1 egg per litre, protective equipment such as gloves or shoes/boots or chemotherapy).
- [c] An arithmetic mean should be determined throughout the irrigation season. The mean value of ≤1 egg per litre should be obtained for at least 90% of samples in order to allow for the occasional high- value sample (i.e. with >10 eggs per litre). With some wastewater treatment processes (e.g. waste stabilization ponds), the hydraulic retention time can be used as a surrogate to assure compliance with ≤1 egg per litre.
- [d] No crops to be picked up from the soil.

8.1.3. Health protection measures

A variety of health protection measures can be used to reduce health risks to consumers, workers and their families and local communities. Hazards associated with the consumption of wastewater-irrigated products include excreta-related pathogens and some toxic chemicals. The risk from infectious pathogens is significantly reduced if foods are eaten after thorough cooking. Cooking has little or no impact on the concentrations of toxic chemicals that might be present. The following health protection measures have an impact on product consumers:

- wastewater treatment;
- crop restriction;
- wastewater application techniques that minimize contamination (e.g. drip irrigation);
- withholding periods to allow pathogen die-off after the last wastewater application;
- hygienic practices at food markets and during food preparation;
- health and hygiene promotion;
- produce washing, disinfection and cooking;
- chemotherapy and immunization.

Wastewater use activities may lead to the exposure of workers and their families to excreta-related diseases (including schistosomiasis), skin irritants and vector-borne diseases (in certain locations). Wastewater treatment is a control measure for excreta- related diseases, skin irritants and schistosomiasis but may not have much impact on vector-borne diseases. Other health protection measures for workers and their families include:

- use of personal protective equipment;
- access to safe drinking-water and sanitation facilities at farms;
- health and hygiene promotion;
- chemotherapy and immunization;
- disease vector and intermediate host control;

- reduced vector contact.

Local communities are at risk from the same hazards as workers, especially if they have access to wastewater-irrigated fields. If they do not have access to safe drinking- water, they may use contaminated irrigation water for drinking or for domestic purposes. Children may also play or swim in the contaminated water. Similarly, if wastewater irrigation activities result in increased vector breeding, then local communities may be affected by vector-borne diseases, even if they do not have direct access to the irrigated fields. To reduce health hazards, the following health protection measures for local communities may be used:

- wastewater treatment;
- restricted access to irrigated fields and hydraulic structures;
- access to safe recreational water, especially for adolescents:
- access to safe drinking-water and sanitation facilities in local communities;
- health and hygiene promotion;
- chemotherapy and immunization;
- disease vector and intermediate host control;
- reduced vector contact.

8.2. Effluent Quality for Irrigation

In Pakistan no specific standards exist for wastewater reuse. Only discharge standards for effluent mixing with water body are available which may be used as a guideline for irrigation purpose. However international standards for irrigation are available which are discussed as follows:

8.2.1. International guidelines and quality criteria for agricultural reuse of wastewater

- Manual of wastewater reuse (USEPA, 2012).
- The WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater 2006.
- ISO Guidelines for treated wastewater use for irrigation projects (ISO-16075-2,2020), EU adopted the same standards.

8.3. Types of irrigation

8.3.1. Sprinkle Irrigation

Sprinkler/spray irrigation is the method of applying water to a controlled manner in that is similar to rainfall. The water is distributed through a network that may consist of pumps, valves, pipes, and sprinklers. Irrigation sprinklers can be used for residential, industrial, and agricultural usage.

Figure 8-2: Sprinkler Irrigation

8.3.2. Surface irrigation

The term "surface irrigation" refers to systems that deliver water to crops using a gravity-fed, overland flow of water. Surface irrigation conveyance and distribution systems are among the first engineering innovations of humans, dating back to more than 6,000 years ago.

Figure 8-3: Surface Irrigation

8.3.3. Drip Irrigation

Drip irrigation involves placing tubing with emitters on the ground along side the plants. The emitters slowly drip water into the soil at the root zone. Because moisture levels are kept at an optimal range, plant productivity and quality improve. Drip irrigation has more commonly been used in commercial nursery and farm operations; however, homeowners are beginning to take advantage of its uses and benefits. As a homeowner, you can use drip irrigation in your vegetable and perennial gardens, and to water trees and shrubs.

The main components of a drip irrigation system include the mainline, valve, sub-main, backflow preventer, pressure regulator, filter, tubing adapters and fittings, drip tubing, emitters, and end caps. The mainline is the pipe that runs from the water source – typically your outdoor faucet – to the valve; and the sub-main runs from the valve to the point where the drip tubing is connected.

Figure 8-4: Types of Irrigation

8.3.4. Health and environmental risks considered for agricultural irrigation:(WHO)

- Ingestion of irrigated crops by consumers.

- Ingestion of droplets (produced by sprinkler irrigation) by workers, bystanders and residents in nearby communities.
- Inhalation of aerosols (produced by sprinkler irrigation) by workers, bystanders and residents in nearby communities.
- Dermal exposure by workers, bystanders and residents in nearby communities.
- Ingestion of soil particles by workers, bystanders and residents in nearby communities.
- Ingestion of pastures and fodder by milk- or meat-producing animals (human and animal health).
- Contamination of drinking water sources.

8.4. Types of crops

As per WHO, USEPA, 2012; ISO-2020, types of crops include:

- **Food crops consumed raw**: crops, which are intended for human consumption to be eaten raw or unprocessed. These include:
- raw fruits and raw vegetables.
- dried fruits and vegetables.
- freshly made fruit and vegetable juices.
- soaked and sprouted beans, other legumes, and grains.

Figure 8-5: Food crops consumed raw

- **Processed food crops:** crops, which are intended for human consumption not to be eaten raw but after a treatment process (i.e. cooked, industrially processed).

Figure 8-6: Food Processed food crops

- **Non-food crops: crops,** which are not intended for human consumption (e.g. pastures, forage, fiber, ornamental, seed, energy and turf crops).

Figure 8-7: Non food crops

8.5. Unrestricted & Restricted Irrigation as per WHO

8.5.1. Unrestricted Irrigation:

- Use of high-quality effluents, instead of freshwater, to irrigate any crop on any type of soil, which means without limitations.
- **Contact and even accidental drinking do not pose health risks.**
- **Crops without any restriction include also vegetables eaten raw.**

8.5.2. Restricted Irrigation:

- **Use of low-quality effluents in limited areas and for specific crops only**
- Restrictions are imposed based on the type of soil, irrigation method, crop harvesting technique, and fertilizer application rate
- Imposed crop limitation must be enforced and controlled.
- Farmers must be trained to handle the low-quality effluent

8.6. WHO water quality guidelines for irrigation

Table 8-3: WHO water quality guidelines for irrigation

Parameter	Value	Unit	Degree of restriction		
			None	Slight to moderate	Severe
TDS		mg/l	< 450	450-2000	> 2000

Parameter	Value	Unit	Degree of restriction		
TSS		**mg/l**	**< 50**	**50-100**	**> 100**
Salinity ECWa		ds/m	< 0.7	0.7-3.0	>3
Sodium(Na+)	Sprinkler irrigation	meq/l	< 3	> 3	
Sodium(Na+)	Surface irrigation	meq/l	< 3	3-9	> 9
Chloride	Sprinkler irrigation	meq/l	< 3	> 3	
Chloride	Surface irrigation	meq/l	< 4	4-10	> 10
Chlorine	**Total residual**	**mg/l**	**< 1**	**1-5**	**> 5**
Boron(B)		mg/l	< 0.7	0.7-3.0	> 3
Iron(Fe)	Drip irrigation	mg/l	< 0.1	0.1-1.5	> 1.5
Mangnanese	Drip irrigation	mg/l	< 0.1	0.1-1.5	> 1.5
Total Nitrogen		**mg/l**	**< 5**	**5-30**	**> 30**
pH				6.5-8	6.5-8
E-COLI cfu/100ml			**≤1000**		**≤10,000**
Helminthes (eggs/100 cm3)			**≤1**		**≤1**

8.6.1. Comparison of Quality guidelines/standards for irrigation according to EPA, WHO, ISO and FAO UN

Table 8-4: WHO water quality guidelines for irrigation

	EPA		WHO		ISO		FAO UN	
Parameter	**Non food crops**	**Processed Food crops**	**Un-restricted**	**restricted**	**food crops**	**Nonfood crops**	**Food crops**	**Non food**
BOD5 (mg/l)	≤10	≤30	-	-	≤ 10	≤ 20	< 10	< 30
TSS (mg/l)	≤ 2 NTU turbidity	≤30	-	-	≤ 10	≤ 25	< 30	< 30
E-COLI cfu/100ml	No detectable	≤200	≤1000	≤10,000	≤100	1000	<14 NMP	<200 NMP
Helminthes (eggs/100 cm3)	-		≤1	≤1	≤1		≤1	

8.7. Treatment Required for wastewater Reuse for Irrigation

To achieve the desired quality of wastewater effluent for irrigation, the treatment process must be comprehensive and multifaceted. The most important aspect to be taken care of while planning any strategy for the reuse of treated sewage water is the detailed qualitative and quantitative analysis of the microorganisms present in it. As large numbers of pathogenic organisms get discharged from the human body in feces, sewage water becomes a potential source for causing many diseases. Sometimes it can lead to the endemic spread of waterborne diseases. Although measures such as chlorination are taken while treating the sewage but often it needs stringent monitoring. Microorganisms present in the wastewater can also seep in the soil with subsequent contamination of ground water.

If heavy metals in wastewater are within PEQS limits the quality of effluent before mixing in water body may be as per PEQS as given below;

Table 8-5: PEQS wastewater effluent quality standards

SR. NO	PARAMETER	UNIT	NEQs (Into inland waters)
1	TSS	mg/l	200
2	TDS	mg/l	3500
3	COD	mg/l	150
4	BOD_5	mg/l	80

8.7.1. Treatment process for reuse of wastewater for indirect use for irrigation

(If effluent is to be discharged to a water body only)

- **Secondary Treatment Process:**

Any secondary treatment process including WSP, ASP or TF or any other process like Oxidation Ditches may be installed. Treated effluent will meet PEQS.

- **Disinfection** of treated effluent. If chlorination is used, residual chlorine should be < 1 mg/L just before mixing into water body. Fecal coliform should be less than 10,000/100mL of treated water. Chlorination is necessary after treatment by restricting residual level to< 1 mg/L because many downstream residents use canal water for drinking purpose.

- **Minimum 1:10 Dilution in a water body**

This will ensure final BOD in water body less than 8mg/l.

In most of the cases US, EU, INDIA use membrane technology even for irrigation of public parks, Golf Courses etc. due to stringent quality standards.

8.7.2. Direct use of treated effluent for irrigation

BOD REQUIREMENT AS PER PEQS:

- For direct use of treated wastewater effluent quality of BOD may be 8 mg/L (the target achieved after 10 times dilution in water body as per PEQS standards for indirect reuse) and to achieve this quality with WSP process is almost impossible therefore, one has to use other treatment process.

Let us see what processes are being adopted by other countries for irrigation.

a) Technologies at WWTP of Surat (Gujrat, India) Municipal Corporation: Planned to add tertiary treatment at all plants by 2030

Table 8-6: Treatment process at Surat

SR.No	Location of treatment plant	CAPACITY (MGD)	PROCESS	Reuse
1	Anjana	27	IFAS	Gardening, Road washing
2	Bhesan	22	IFAS	Agriculture use
4	Karanj	31	IFAS	Gardening, Road washing
5	Singanpore	34	IFAS	Gardening, Road washing
7	Asarma	3.3	MBBR	Gardening, Road washing

Integrated fixed film activated sludge (IFAS)
Moving Bed Biofilm Reactor (MBBR)

Sequential Batch reactor (SBR)

b) Chandigarh, India wastewater reuse for irrigating all parks of the city

There are 3 WWTP plants in Chandigarh having following technology for secondary treatment:

- MBBR
- AS
- UASB

All above plants are producing effluent BOD below 40mg/l but, their effluent standards are very stringent now (10mg/l) therefore, they have started upgrading with tertiary treatment (**Sand filtration or UF and disinfection).**

MBBR process for BOD/COD reduction only

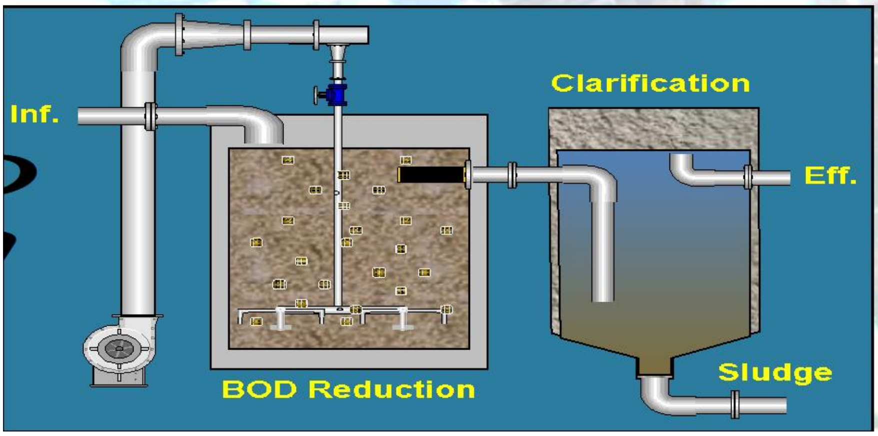


Figure 8-8: MBBR working

INTERGRATED FIXED FILM ACTIVATED SLUDGE(IFAC)

Integration of both suspended growth and attached growth process for < 10 mg/l BOD plus De-nitrification(after clarification).

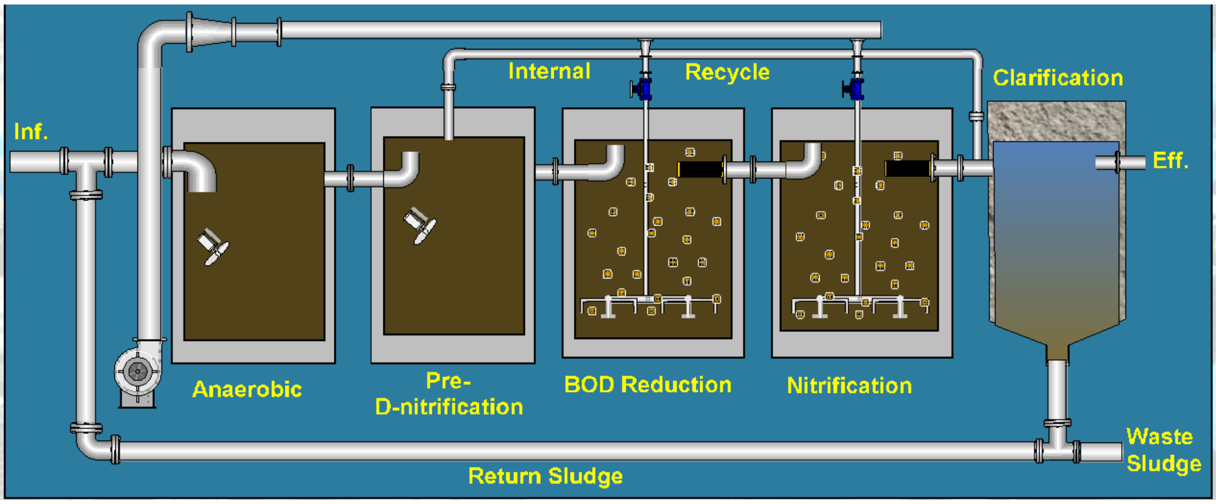


Figure 8-9:IFAC process

Small foot print. Quick process for BOD, Nitrogen and Phosphorus removal. Return sludge involved

UASB REACTOR

- UASB uses an anaerobic process whilst forming a blanket of granular sludge which suspends in the tank.
- Wastewater flows upwards through the blanket and is processed (degraded) by the anaerobic microorganisms.
- The upward flow combined with the settling action of gravity suspends the blanket with the aid of flocculants.
- The blanket begins to reach maturity at around three months.
- Organic components (COD) are converted to $CH_4 + CO_2$ + BIOMASS

Figure 8-10: UASB Reactor

Figure 8-11: Sludge Granules

Advantages of UASB

Requires smaller reactor volume
Simple construction and low operation and maintenance.
Robustness in treatment efficiency and wide applicability from very small to very large scale
Energy is generated as methane/hydrogen gas.
Low sludge production as compared to aerobic processes
Ability to withstand organic shock loads

c) PROCESS OF PASAKOY WWT ISTANBUL TO MEET IRRIGATION QUALITY STANDARDS

- The process includes Oxidation Ditches Plant, rapid sand filtration and finally UV disinfection. Final effluent is used for irrigation of plants in green belts of the City.

Figure 8-12: Treatment Process used at Pashakoy Istanbul

9. REFERENCES

- *Von Sperling: Biological wastewater treatment in warm climate regions.2005*
- *Waste Stabilization Ponds By: Miguel Peña Varón Universidad del Valle, Instituto Cinara. Cali, Colombia*
- *Duncan Mara School of Civil Engineering, University of Leeds. Leeds, UK*
- *https://www.sciencedirect.com/science/article/pii/S2352484720315833*
- *https://www.lenntech.com/processes/mbbr.htm*
- *US EPA "wastewater Technology Fact Sheet Oxidation Ditches"*
- *Minnesota Pollution Control Agency: Stabilization Pond Systems: Operations • Maintenance • Management*
- *https://www.sswm.info/.KAYOMBO%20et%20al%202004%20Waste%20Stabilizati…*
- *EPA: Constructed Wetlands Treatment of Municipal Wastewaters*
- *Advantages-Applications-of-MBBR-Technologies.pdf*
- *WHO GUIDELINES FOR THE "SAFE USE OF WASTEWATER, EXCRETA AND GREYWATER, Volume-1"*
- *Punjab Environmental Quality Standards*
- Surat Municipal Corporation: Reuse & Recycle of Treated Wastewater Action Plan 2019
- *(ISKI) Istanbul Water and sewerage Administration*
- *EPA 2012 Guidelines for water reuse*
- www.fao.org › ... Wastewater Treatment
- *Council Directive (9 1 /271 /EEC) concerning urban waste water treatment .pdf*