Lesson C1

Operation and management of wastewater treatment plants

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Table of Content

1. Overview and summary

This lesson is focused on the operation and maintenance of wastewater treatment plants: in the first part, the basic principles included into the *Operation and Management Manual* – the document that should always be annexed to any WWTP design – are presented; next section is addressed to the description of the main procedures to be usually applied for any WWTP operation, enlighting all the most common problems, troubleshootings and their solutions, related to all the treatment processes.

2. Operation and Maintenance Manual

The purpose of the Operation and Maintenance (O&M) Manual is to provide WWTPs' operators with the proper understanding of recommended operating techniques and procedures, and the references necessary to efficiently operate and maintain their facilities.

The O&M manual shall contain all information necessary for the plant operator to properly operate and maintain the collection, treatment and disposal systems in accordance with all applicable laws and regulations. A copy of the approved O&M manual shall be maintained at the treatment plant at all times.

The O&M manual shall include the following:

a) Introduction
b) Permits and Standards
c) Description, Operation and Control of Wastewater Treatment Facilities
d) Description, Operation and Control of Sludge Handling Facilities
e) Personnel
f) Sampling and Laboratory Analysis
g) Records and Reporting
h) Maintenance
i) Emergency Operating and Response Program
j) Safety
k) Utilities

2.1 Introduction

The introduction shall include a general description of the nature of the establishment (e.g. office park, commercial strip mall, etc.) that is served by the wastewater treatment plant (WWTP). Included with the introduction shall be the location of the WWTP and any environmentally sensitive areas, a locus map should be provided.

2.2 Permits and Standards

The Permits and Standards section shall discuss the type of permit issued and include a copy of all permits. A detailed description of responsibilities of the owner, operator and consulting engineer necessary to meet all permit conditions shall be provided.

2.3 Description of Wastewater Treatment Facilities Operation & Control

The substance of how to operate the treatment facility lies within this section. This section is intended to provide a description of the various treatment plant components and their function. Each component should be presented in a sequential order and discussed individually. The narrative should discuss the treatment system from the point of generation (including the conveyance system) through the treatment processes to final disposal.

The method for operating each unit of the treatment system shall be discussed in this section. For example, if pretreatment tanks are proposed then how often they require sludge removal should be mentioned.

The O&M manual shall include the manufacturer's operating, maintenance and repair instructions for all process units and appurtenances associated with the WWTF such as:
motors, pumps, valves, blowers, bearings, drive assemblies, control panels, electrical systems, alarms, piping, tankage, and equipment. This information can be incorporated into the body of the Operation and Control of Wastewater Treatment Facilities section or included as appendices. This section shall go on to provide detailed instructions on treatment plant operation including chemical storage and handling, process testing, standard operational mode, optional modes available (such as seasonal operations), process controls and safeguards.

If the WWTP includes storage of chemicals that are required as part of the treatment process (e.g. methanol) the O&M must provide information such as name, address, and telephone number for each chemical supplier.

2.4 Description of Operation & Control of Sludge Handling Facilities

All WWTPs generate waste solids that require handling separate from the wastewater treatment system. This section shall provide a description of the sludge handling and disposal requirements including the name and telephone number of the sludge disposal facility and record keeping requirements. For any process unit that either generates or stores waste solids an expected removal frequency and means of removal shall be provided.

2.5 Personnel

The owner of a WWTP must employ sufficient personnel to ensure the proper operation of the facility. A description of the number and qualifications of the personnel necessary for proper and continuous operation of the collection, treatment and disposal systems shall be given. It shall include the Grade of the Chief Operator and that of any backup or staff operators. The duties and responsibilities of the staff shall be provided. It shall include the number of days per week and hours per day the facility shall be staffed, holiday and weekend staff coverage, and on-call and emergency operating personnel.

2.6 Sampling and Analysis

A listing of all sampling (operational and compliance monitoring) and analyses required together with appropriate protocols for proper sampling, storage, transportation, and analysis shall be provided. In addition, a quality control/quality assurance plan shall be developed. The sampling and analysis plan must include a description of sampling that is reflective of the conditions of the permit for: influent, effluent, and eventually groundwater monitoring wells.

The plan must include the parameter that is being tested for (e.g. pH, BOD_5, COD, etc.), its frequency of testing (e.g. daily, weekly, monthly, etc), and the method for testing (e.g. Standard Methods, Official National Methods, etc.). The method of sampling (e.g. grab or composite) shall also be stated in the sampling plan. Process control testing and the parameter and frequency must also be incorporated. The sampling and analysis plan must include locations of where testing must be performed to ensure that process units are operating properly and efficiently. The sampling plan for the groundwater monitoring wells must state the location of the well and its designation number.

If analysis is done on site or transported to a certified lab then this must be so stated in the plan. Any on-site equipment such as pH meters must have documentation for the proper operation of such equipment including calibration information. If chemicals or buffer solutions are required for calibrating equipment they must be stored and handled according to manufacturer's recommendations.

2.7 Records and Reporting

A listing of all reporting requirements and location and method of record keeping shall be included. The Records and Reporting section shall reference daily log of plant operations, process changes and equipment maintenance. Copies of daily logs as well as any inspection reports shall be kept at the facility at all times.

2.8 Maintenance

The Maintenance section shall include a list of spare parts and supplies that shall be available to the operator for the maintenance and repair of the treatment plant and related appurtenances. This section shall include a chart itemizing all equipment within the treatment facility and its associated maintenance action (e.g. lubricate motor bearings) and the frequency of such action (e.g. every 6 months). The chart should include provisions for including notes or comments by the operator. Included in this section shall be a lubrication chart, which details for all equipment routine inspections, lubrication and adjustment, which must be performed by the operator.

It should be noted that only equipment or materials associated with the treatment plant are allowed to be stored within the confines of the WWTP. The treatment plant should not be used as a storage structure for items not related to the WWTP.

2.9 Emergency Operations & Response

An emergency operating and response program shall be discussed. It shall detail procedures to be followed in the event of the following emergency situation: power failures, storms, flooding, hydraulic overload/ruptures, fire, explosions, equipment failure, spills of hazardous materials, maintenance shutdowns, and personnel injury. A description of who should be notified, and when, for each emergency situation shall be provided along with an appropriate telephone number.

The procedures to follow shall include information as to identifying the emergency condition, investigating the severity of the emergency, actions to be taken and notification of responsible authorities, corrective actions to rectify the situation, and necessary follow-up. Follow-up procedures should include feasible measures to prevent or minimize the likelihood of a similar situation from reoccurring.
At a minimum the following telephone numbers shall be incorporated into the Emergency Operations & Response Section: local fire department, local police department, ambulance, poison control center, Regional Office of the Department and local Board of Health. This section should state where the phone numbers would be posted within the treatment plant.

2.10 Safety

A description of proper material handling and precautionary safeguards shall be included. This shall include a listing of an instruction for use of all necessary safety and first aid equipment. An itemized list of safety equipment shall be provided. Training for personnel is a key component of a proper safety program. The Safety section must include what training (e.g. OSHA, first-aid, CPR) is required for all staff employed to work within the WWTP. All Material Safety Data Sheets (MSDS) for any chemicals stored on site must be included in the O&M as well as available within the WWTP.

2.11 Utility

A listing and directory providing names and notification requirements for water, electric, gas and telephone services shall be included in the O&M manual.

3. Wastewater treatment plant (WWTP)

Wastewater treatment or sewage treatment is the process that removes the majority of the contaminants from waste-water or sewage and produces both a liquid effluent suitable for disposal to the natural environment and a sludge. To be effective, sewage must be conveyed to a treatment plant by appropriate pipes and infrastructure and the process itself must be subject to regulation and controls. There are many and various forms of treatment processes. The site where the processes are conducted is called a wastewater treatment plant (WWTP). The flow scheme (see figure 1) of a conventional WWTP is generally the same in all countries and exists our of following physical-chemical elements:

- Mechanical treatment;
    - Influx (Influent)
    - Removal of large objects
    - Removal of sand
    - Pre-precipitation

- Biological treatment;
    - Oxidation bed (oxidizing bed) or Aerated systems
    - Post precipitation
    - Effluent

- Chemical treatment (this step is usually combined with settling and other processes to remove solids, such as filtration.

Besides the physical-chemical classification the technical classification is based on the steps, which are performed one by one other:

- **Primary treatment** (see figure 1): to reduce oils, grease, fats, sand, grit, and coarse (settle able) solids. This step is done entirely with machinery.
- **Secondary treatment** (see figure 1) is designed to substantially degrade the solved content of the sewage within a biological degradation system, such as activated sludge systems. These systems use the capability of microorganism to degrade solved components in water. The final step in the secondary treatment stage is to separate the used biological media from the cleared sewage water with a very low levels of organic material and suspended matter.
- **Tertiary treatment** or advanced treatment (not in figure 1) is yet not applied widely. It provides a final stage to raise the effluent quality to the standard required before it is discharged to the receiving environment. More than one tertiary treatment process may be used at any treatment plant. In most cases it is a further nitrogen or phosphate elimination and/or a disinfection. Additional steps like lagooning or constructed wetlands are also counted as tertiary step if they are used after secondary treatment.

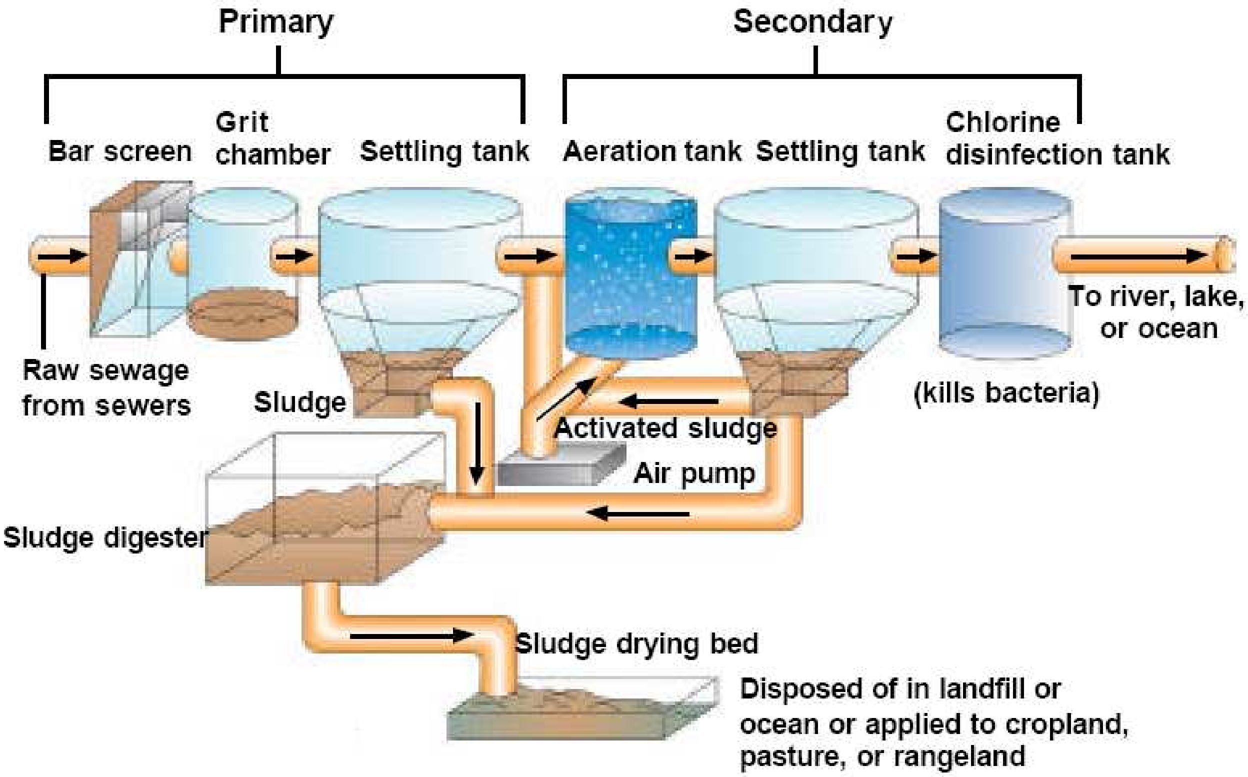

Figure 1: Wastewater treatment plant (Queens University 2004)

3.1 Screening

Screening is a primary treatment in a wastewater treatment process. Screenings are the material retained on bar racks and screens. The smaller the screen opening, the greater will be the quantity of collected screenings (see figure 2). In table 3.2 typical data on characteristics and quantities of screenings removed from urban wastewater with fine bar (mechanically cleaned). In table 3.1 some typical information about operations bar racks are reported.

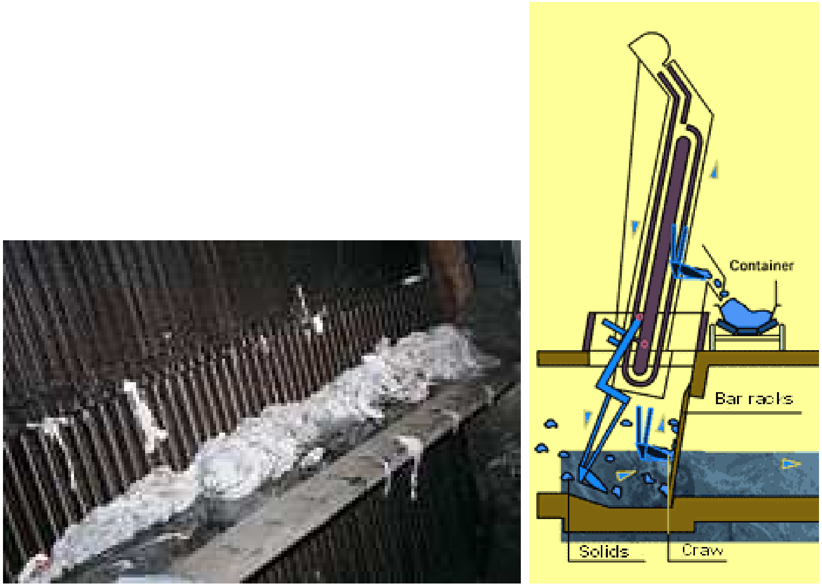

Figure 2: Example for a mechanical bar screen (Source: Entwässerungsbetriebe Mainz)

Tab. 3.1 Typical design information for manually and mechanically cleaned bar racks

		Manually cleaned	Mechanically cleaned
Bar size:			
Width	[mm]	5 – 15	5 – 15
Depth	[mm]	25 – 75	25 – 75
Clear spacing between bars	[mm]	20 – 60	10 – 30
Slope from vertical	[°]	45 – 60	70 – 90
Approach velocity	$[m\ s^{-1}]$	0.3 – 0.5	0.5 – 1
Allowable headloss	[m]	0.1 – 0.2	0.1 – 0.2

Tab 3.2 Typical information on the characteristics and quantities of screenings removed from urban wastewater with fine bar (mechanically cleaned)

Clear spacing between bars [mm]	Volume of screenings [m^3 PE^{-1} y^{-1}]	Suspended solids removal [%]	BOD_5 removal [%]
15	$2\ 10^{-3} – 4\ 10^{-3}$	1 – 3	-
10	$3\ 10^{-3} – 6\ 10^{-3}$	2 - 5	1 – 3

The quantity of collected screenings varies depending on the type of the screen and, in particular, on the type of sewer system and wastewater characteristics. Their efficiency depend on the spacing between the screen bars and is named as follows:

- Fine screening: spacing < 10 mm
- Medium screening: spacing 10 - 40 mm
- Coarse screening: spacing > 40 mm

Usually a fine screening is preceded by a medium or course screening for protection.

For coarse screens, the quantity of removed screenings ranges between 0.005 e 0.05 m^3 per 1000 m^3 of treated wastewater. These values, in case of combined sewers, could be much higher during storm events. For fine screens the quantity of removed screenings can reach value up to 0.3 – 0.5 m^3 per 1000 m^3 of treated wastewater.

The collected screenings characteristics are very different; generally the misture content ranges between 70 al 90 % and specific weight between 700 – 900 kg m^{-3}. In case of urban wastewater putrescible matter is contained within the screenings therefore they must be handled and disposed quite quickly.

The headloss increases when the screen collects material, and cleening operation are needed. The approaching velocity should be higher than 0.6 m s^{-1}, in order to avoid sand deposition or other suspended material. In table 3.1.3 a typical screen operation sheet is reported; the reporting frequency depends on the WWTP size; details on routine inspections, lubrication and adjustment, performed by the operator, should be reported as well.

Tab 3.1.3 Screen operation sheet

Month: ……..; Year: ……. ; Operator: ……………………….; Item nr: ………………

Day	Hour	Flow rate [m^3 h^{-1}]	Screenings characteristics			Operational parameters		Notes
			Quantity [m^3 d^{-1}]	Moisture [%]	VS [%]	Headloss [mm]	Velocity [m s^{-1}]	
1								
2								
31								
Monthly mean								

3.1.1 Screening troubles and remedial actions

3.1.1.1 Sand accumulation in the screen channel

Symptoms
- Sand presence in the collected screenings
- Water level increase in the screening channel
- Sand reduction collected form the grit chamber

Main causes
- Reduced approach velocity
- Obstruction occurrence in the screening channel

Investigations and analyses
- Confine the area where sand accumulates
- Measure the approach velocity corresponding to the different wastewater flow rate;
- Examine the as-built drawings to check the presence of some shape irregularity in the approaching channel

Remedial actions
- If the approaching velocity is less than 0.5 m s^{-1} then an increase is needed: a temporary solution could be the flow rate increase through a recycle flow, a reduction of the screening channels (if there are more than two working in parallel) a water level reduction modifying the out flow weir
- Empty the screen channel and remove all the bottom irregularities

3.1.1.2 Solid transport though the screen

Symptoms
- Regular clogging of the pipes downstream the screen
- Finding inappropriate materials in the pump impeller shown by high electrical input and unusual noises

Main causes
- Solids removal not effective
- Unsuitable pumps
- Incorrect piping design or installation

Investigations and analyses
- Check the presence of solids in the water flow downstream the screen
- Check the pump water flow

Remedial actions
- As temporary solution reverse the pump rotational movement
- Modify the suction pipe setting up a protection barrier
- Replace the pump
- Modify the solid removal system upstream

3.2. Grit removal

The goal of grit removal is to separate gravel and sand and other mineral materials down to a diameter between 0.2 and 0.1 mm. Grit chambers are provided to (a) protect downstream moving mechanical equipment from abrasion (b) reduce formation of heavy deposits in pipe line and (c) reduce the frequency of digester cleaning caused by excessive accumulation of grit.

There are three general types of grit chamber:

1. horizontal-flow – rectangular configuration
2. horizontal-flow – square configuration
3. aerated; (see figure 3 and 4)

The use of vertical flow chambers have shown an insufficient separation of very fine grained sand fraction.

The quantity of removed grit will vary depending on the type of sewer system, the characteristics of the drainage area, etc. The amount of removed gravel is different plant by plant.

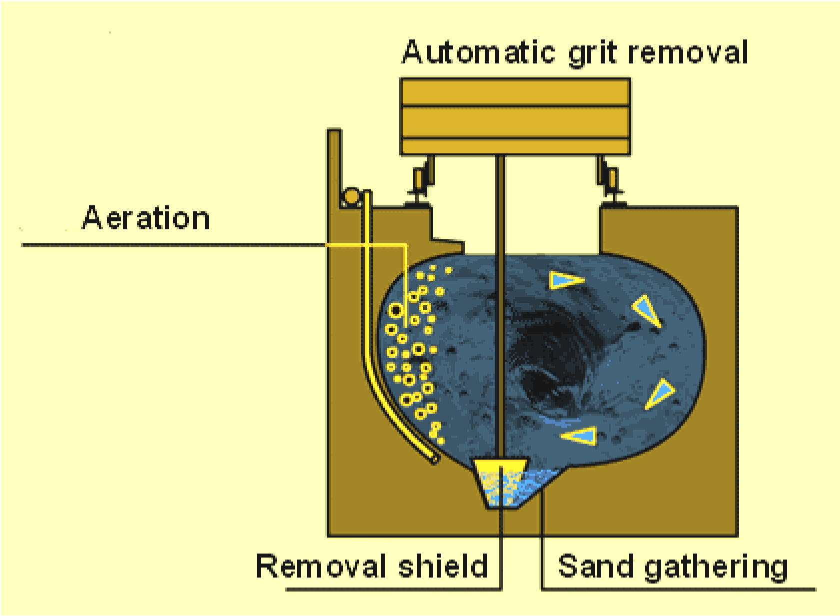

Figure 3: Example for an aerated grit chamber (Source: Entwässerungsbetriebe Mainz)

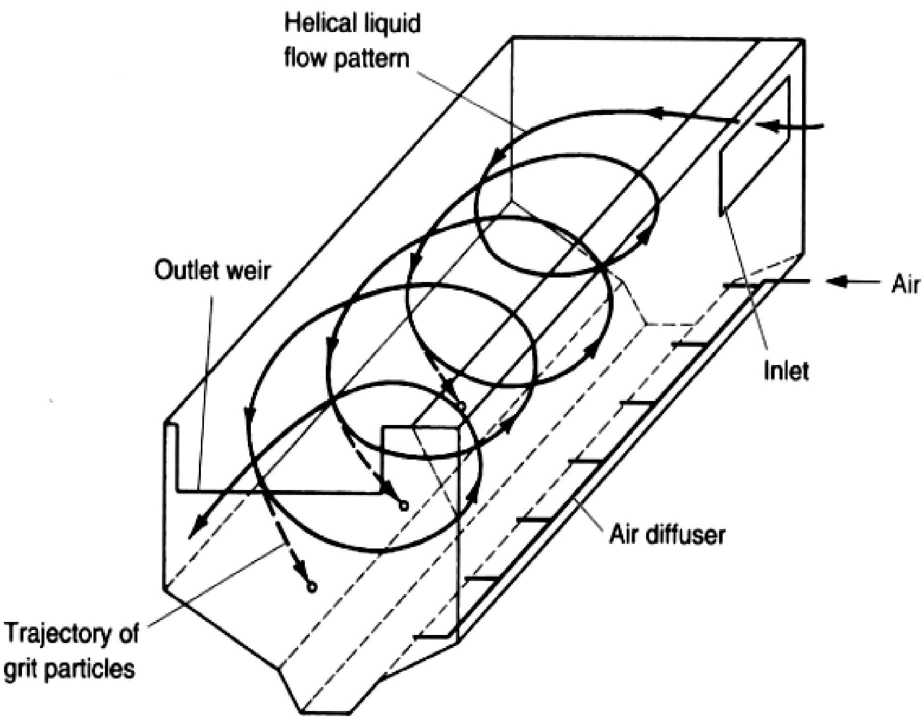

Figure 4: Aerated grit chamber (Crites and Tchobanoglous, 1998)

In aerated grit chambers, grit is removed by causing the wastewater to flow in a spiral pattern, as shown in figure 4. Air is introduced in the grit chamber along one side, causing a perpendicular spiral velocity pattern to flow through the tank. Heavier particles are accelerated and diverge from the streamlines, dropping to the bottom of the tank, while lighter organic particles are suspended and eventually carried out of the tank.

In table 3.2.1, some typical values by different authors for combined sewer systems are shown.

Tab. 3.2.1 Typical amounts of collected grit (combined sewer)

Volume of grit [l PE^{-1} yr^{-1}]	Volume of grit [l m^{-3}]	reference remark
40	0.02 - 0.2	ATV-Hanbuch, 1997 average: 0.06 l / m³
2.4 – 58.8		Londong, 1990
2		Imhoff, 1993 high-density areas
5		Imhoff, 1993 low-density areas
	0.01 – 0.1	Passino et al. (1999)
	0.004 - 0.2	Tchobanoglous, 2003 aerated grit chamber

Total amount of mineral material inside influx of grit chamber is between 10 and 60 g per m³ of wastewater (grain size ranges between 0.09 – 3.0 mm). The use of a sieve in upstream decreases mass of separated solids in grit chamber. (ATV-Handbuch, 1997).
In case of combined sewer, over a dry period (low flow velocity) sand can settle down in the sewer pipes: a hard rain causes an increasing flow speed and the sand is flushed into wastewater treatment plant. Thus, the highest amounts of sand reaches the plant with stormwater.

In case of separate sewer, the quantity of grit will be less than that expected for combined sewer (typical value is 0.5 l m^{-3} of wastewater). The moisture content of the collected grit ranges between 15 e 40 %; volatile content, on dry basis, ranges between 20-50 %.

In table 3.2.2 a typical grit chamber operation sheet is reported; the reporting frequency depends on the WWTP size; details on routine inspections, lubrication and adjustment, performed by the operator, should be reported as well.

Tab 3.2.2 Grit chamber operation sheet

Month: ……..; Year: ……. ; Operator: ……………………….; Item nr: ……………….

Day	hour	Flow rate [$m^3 h^{-1}$]	Removed grit			Operational parameter				Notes
			Quantity [%]	Moisture [%]	VS [% TS]	Velocity [$m h^{-1}$]	HRT [min]	Air flow rate [$Nm^3 h^{-1}$]	Power [kW]	
1										
2										
31										
Monthly mean										

3.2.1 Grit removal troubles and remedial actions

3.2.1.1 Grit transport though the grit chamber

Symptoms
- Rapid abrasion of moving mechanical equipment downstream the grit chamber
- High inert content in the biological aeration tank
- Quantity of collected grit smaller than normal conditions

Main causes
- High velocity and / or too short hydraulic retention time

Investigations and analyses
- Measure inorganic suspended solids inflowing and out flowing the grit chamber at different wastewater flow rates
- Measure the velocity corresponding to the different wastewater flow rates;
- Measure the air flow rate in case of aerated grit chamber

Remedial actions
- In the rectangular horizontal-flow grit chamber, increase the frequency of grit removal in order to increase the available water section
- Reduce the velocity of roll or agitation
- Increase the number of the grit chamber
- Reduce air flow rate in case of aerated grit chamber
- Replace the pump
- Modify the solids removal system upstream

3.2.1.2 High content of organic material in the collected grit

<u>Symptoms</u>
- Quantity of grit removed higher than the normal
- Dark colour of the grit removed
- Mixture more doughy than the normal
- Foul smell from the collected grit

<u>Main causes</u>
- Low velocity and / or too high hydraulic retention time

<u>Investigations and analyses</u>
- Analyse, daily, the volatile content in the collected grit
- Measure the velocity corresponding to the different wastewater flow rate
- Measure the air flow rate in case of aerated grit chamber

<u>Remedial actions</u>
- If possible, reduce the number of the grit chambers working in parallel
- In case of rectangular horizontal-flow grit chambers, reduce the water section or modify (reduce) the water level in the chamber by regulating the weir
- In case of aerated grit chamber increase the air flow rate
- Increase the velocity of roll or agitation

3.3 Sedimentation

The main goal of sedimentation is to remove readily settleable solids and floating materials (not removed in the upstream treatment phases) thus reducing the suspended solids content; so quiet conditions are set up in the sedimentation basin: collected solids are subsequently sent to the sludge treatment processes, and (in case of secondary sedimentation) partially recycled.

The sedimentation process takes place in a settling tank, which is a circular or rectangular basins made of concrete or iron, having the bottom lightly sloped towards a zone where the sludge is conveyed by appropriate withdrawal devices.

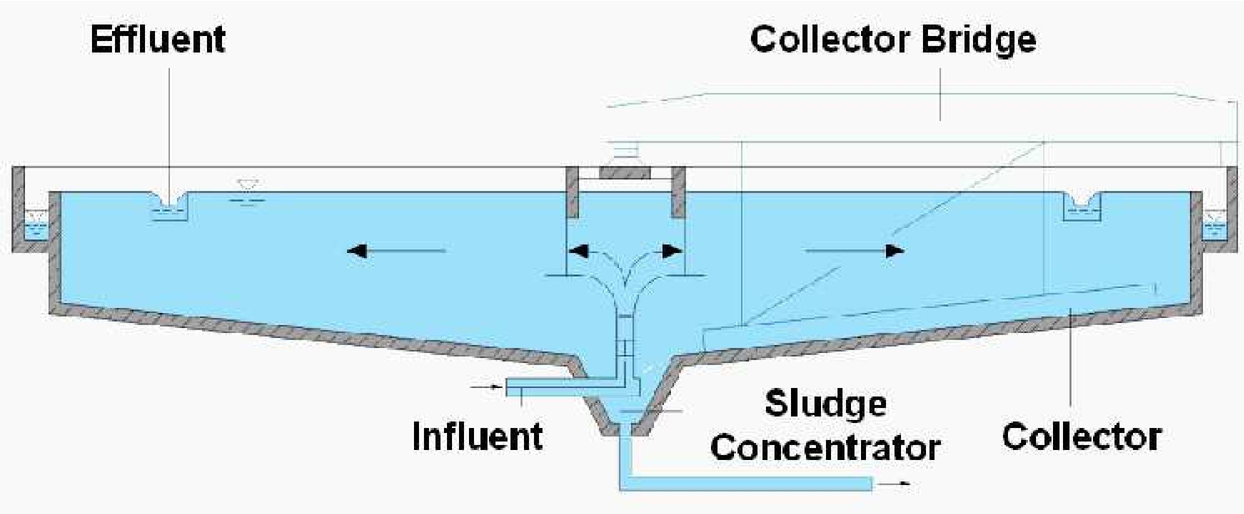

Figure 5: Example for a circular sedimentation tank (Source: Universität Stuttgart)

Sedimentation tanks are designed to operate continuously. Primary sedimentation tanks may provide the principal degree of wastewater treatment, or may be used as a preliminary step in further treatment of the wastewater. When used as the only means of treatment (not authorized in most developed countries), these tanks provide for removal of settle able solids and much of the floating material. When used as a preliminary step to biological treatment, their function is to reduce the load on the biological treatment units. Efficiently designed and operated primary sedimentation tanks should remove 50 to 65 percent of the suspended solids and 25 to 40 percent of the biochemical oxygen demand.

Tab. 3.3.1 Typical operational data (HRT and overflow rate) for different type of clarifier

	HRT [h]	Overflow rate [$m^3\ m^{-2}\ h^{-1}$]
Primary Sedimentation	1,5 – 2,0	0,8 - 1,2
Primary Sedimentation upstream the Trickling filters	3,0 – 4,0	0,5 - 0,8
Secondary Sedimentation downstream the Trickling filters	3,0	0,5 - 0,8
Secondary sedimentation	3,0	0,5

The BOD and TSS removal efficiency depends on the clarifier characteristics and on the above mentioned parameters. Basically, in a primary clarifiers, removal efficiency for BOD and TSS are mainly related to the hydraulic retention time (HRT) and the its influent concentration.

In table 3.3.2 a typical clarifier operation sheet is reported; the reporting frequency depends on the WWTP size; details on routine inspections, lubrication and adjustment, performed by the operator, should be reported as well.

Tab. 3.3.2 Clarifier operation sheet

Month: ……..; Year: ……. ; Operator: ………………………; Item nr: ………………															
			Sludge characteristics			Operational parameter				Efficiency				
Day	hour	Flow rate	Quantity	TSS	VSS	Overflow rate	HRT	Weir loading rate	Solid loading rate	TSS in	TSS out	BOD in	BOD out	Notes
		[$m^3 h^{-1}$]	[$m^3 d^{-1}$]	[$g m^{-3}$]	[$g m^{-3}$]	[$m h^{-1}$]	[h]	[$m^3 m^{-2} h^{-1}$]	[$kg m^{-2} d^{-1}$]	[$g m^{-3}$]	[$g m^{-3}$]	[$g m^{-3}$]	[$g m^{-3}$]	
1														
2														
3														
31														
Monthly mean														

3.3.1 Sedimentation troubles and remedial actions

3.3.1.1 Presence of septic sludge, containing bubble gas, on the water surface

Symptoms
- Presence of floating material on water surface
- Emanation of sulphides smell from clarifier

Main causes
- Sludge degradation due to high hydraulic retention time
- The trouble could take place in a limited zone of the clarifier due to the problems of the sludge collector mechanism.

Investigations and analyses
- Measure TSS in the settled sludge after sludge removal operation and if it is too high extend the extraction time
- Check the sludge collector mechanism

Remedial actions
- Increase the scraper velocity
- Increase the extraction time or the frequency of the sludge removal

3.3.1.2 Low settleable solids removal efficiency

Symptoms
- % removal lower than the normal
- Presence of suspended solids in the effluent

Main causes
- High overflow rate
- Presence of short-circuit in the clarifier

Investigations and analyses
- Measure TSS content in the clarifier inflow and outflow
- Measure HRT, overflow rate and compare with the design ones
- Check the possibility of dead zone presence and eventually evaluate with tracer test

Remedial actions
- If the trouble is caused by the high overflow rate, evaluate the possibility of realize another clarifier or equalization tank
- If the trouble is caused by short-circuit, modify the flow characteristics installing screens and enhancing the inlet and outlet distribution systems

3.3.1.3 Low floatable material removal efficiency

Symptoms
- Presence of oils and greases in the clarifier effluent

Main causes
- Incorrect skimmer operation

Investigations and analyses
- Check the state of the skimmer, and the correctness position
- Check the oil and grease content in the incoming wastewater and compare it with the design data

Remedial actions
- Install a screen in the clarifier: floating materials exceed the outlet weir, and therefore periodical screen cleaning operation are needed
- Install sprinkler in order to convey floating material to the extraction zone
- In case of wastewater containing high quantity of oil and grease evaluate the chance of installing a flotation unit upstream the clarifier

3.3.1.4 Excessive sedimentation in the clarifier approaching channel

Symptoms
- Solid presence in the clarifier approaching channel and/or distribution system

Main causes
- Low velocity in the approaching channel

Investigations and analyses
- Measure the approach velocity corresponding to the different wastewater flow rate;

Remedial actions
- Reduce the channel section or increase the turbulence in the approaching channel through recycled wastewater or air
- Enhance the grit chamber efficiency

3.3.1.5 Problems during sludge extraction

Symptoms
- Clogging of the extraction line
- Incorrect operation of the extraction sludge pumps
- Sand presence in the clarifier

Main causes
- High content of sand or clay
- Low velocity in extraction sludge line

Investigations and analyses
- Measure the sand and clay content in the collected sludge
- Evaluate flow velocity in the extraction pipe

Remedial actions
- Back-wash the clogged line
- Enhance the grit chamber efficiency
- Remove the sludge more frequently, trying to remove curves and valves
- If needed reduce the sludge pipe diameter

3.3.1.6 Sludge presence in the final effluent (secondary clarifier)

Symptoms
- High TSS content in the secondary clarifier effluent

Main causes
- Bad sludge settling characteristics
- High overflow rate
- Not properly functioning of the scraper

Investigations and analyses
- Measure the TSS content in the clarified effluent
- Measure the recycle and the waste sludge flow rate
- Check the installation correctness of the outflow weir, in particular the regularity along all the weirs

Remedial actions
- Enhance the weir layout and eventually place some screen wind
- Increase the sludge extraction and recycle flow rate

3.3.1.7 Floating sludge presence in the secondary clarifier

Symptoms
- High TSS content in the secondary clarifier effluent
- Floating sludge presence in the secondary clarifier

Main causes
- Denitrification process in the secondary clarifier

Investigations and analyses
- Assess the nitrification process measuring ammonia, nitrite and nitrate concentration in the effluent of the aeration tank
- Evaluate the HRT in the aeration tank
- Evaluate the sludge retention time in the clarifier

Remedial actions
- Reduce SRT
- Reduce sludge retention time in the clarifier

3.4 Activated Sludge

Activated sludge treatment step takes place into aeration tanks (activated sludge tanks), whose footprint shape has to be defined according to the aeration devices to be installed (see figure 6). Rectangular tanks have to be realised when diffused aeration devices are installed: the ratio width/height ranges between 1 and 2, the lowest values in the case of diffusors installed along only one of the tank's sides; all the edges have to be round shaped in order to avoid dead zones into the tank.

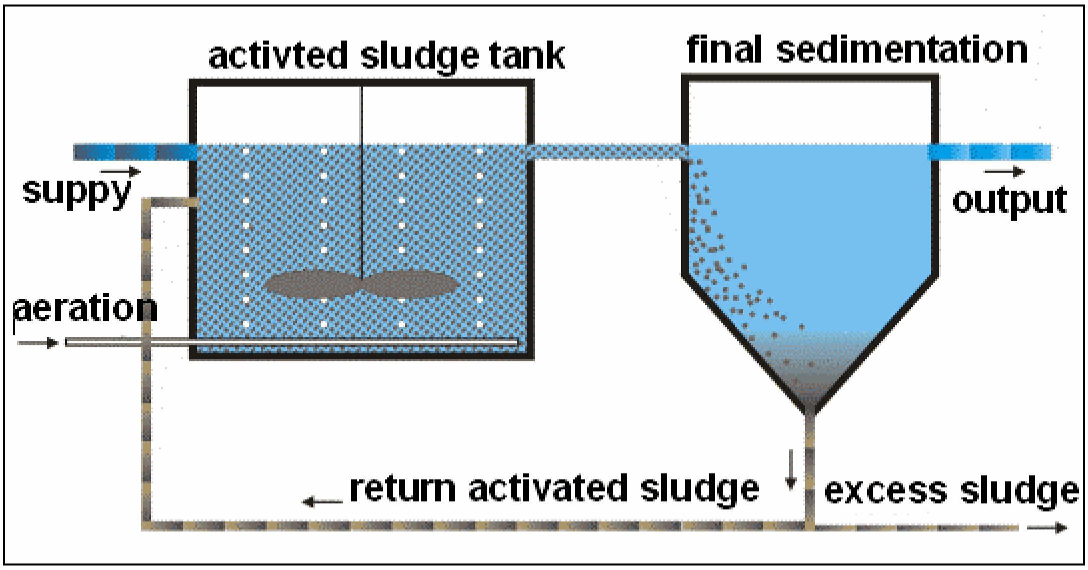

Figure 6: Example for an activated sludge process

The activated sludge process uses microorganisms to feed on organic contaminants in wastewater, producing a purified effluent. The basic principle behind all activated sludge processes is that as microorganisms grow within metabolizing soluted organic material. They form particles that clump together. These particles (flocks) in most cases are able to settle, so that they can separated with a simple settling process, which works according to the same principle as the pre-settling. Wastewater supply is mixed with return of activates sludge (see figure 6) containing a high proportion of organisms taken from the final sedimentation. This mixture is stirred and injected with large quantities of air, to provide the oxygen demand of microorganisms and keep solids in suspension. After a period of time, mixed liquor flows to a clarifier, which is in most cases a settling tank. In special cases also a flotation tank or membranes can be used to separate microorganisms. Partially cleaned water flows on for further treatment if needed. The resulting settled solids, the activated sludge, are returned to the first tank to begin the process again. Due to the fact, that during the process microorganisms grow, the excess sludge has to be removed out of the system to held the microorganisms concentration nearly constant.

When mechanical aeration devices are installed, circular shapes can be chosen as well, especially in the case of small WWTPs. In such cases, the ratio between the width (or the diameter) and the height can range from 1,5 to 5 according to the size of the mechanical aerator(s). A good rule is to split the whole reaction volume into different units (except for very small sized plants). Rectangular shaped tanks, when different units are placed side by side, offer the advantage to allow a lower footprint occupation.
Water level into the tanks is fixed through adjustable weirs (level excursion of about 10 cm, to be expected especially in case of mechanical aerators) to the secondary settling unit.

The tanks' bottom should have a slight slope to one or more shafts where submerged pumps aimed to the periodic tanks' empty for maintenance can be installed. Diffused aeration systems consist of submerged diffusors, air pipes and blowers. Each system has to be chosen according to the air bubbles size and to the air immission depth. Both these parameters affect the technical and the economical design in a very noticeable way: fine bubbles devices can increase the aeration efficiency due to the higher water-air contact surface but at the same time they are more expensive and an additional air pre-treatment is always required (air filtration and oil removal); moreover, the higher is the air immission depth the higher is the oxygen transfer rate, but the blower size increases as well.

During operation breaks, sludge settling can cause air blowers clogging, therefore the system should allow an easy removal of the air diffusors for maintenance. Usually, air diffusors are installed on the tanks' bottom, sometime only along one side in order to increase the turbolence inside the mixed liquor. Coarse bubbles devices consist of perforated pipes (5 -10 mm diameters) or coarse diffusors.

Aeration and Mixing mechanical devices consist of equipment that allow a deeper contact between air and mixed liquor into the tank. Basically, mechanical aerators can be classified into two types:

- *Mechanical aerators with vertical axis*
- *Mechanical aerators with horizontal axis*

Both of them can be classified into submerged and superficial ones.

Basic parameters that characterize the activated sludge process are:

- HRT, Hydraulic Retention Time into the aeration tank
- TSS into the mixed liquor
- Organic Load referred to the biomass
- Volumetric Organic Load
- SRT, Sludge Retention Time
- Recycle Ratio
- Type of flow into the tank (completely stirred, plug flow)
- Aeration System

Typical operational data for different activated sludge process are presented in table 3.4.1.

In table 3.4.2 a typical aeration basin operation sheet is reported; the reporting frequency depends on the WWTP size; details on routine inspections, lubrication and adjustment, performed by the operator, should be reported as well.

Tab. 3.4.1 Typical operational data for different activated sludge process

Process	Aeration system	Type of reactor	F/M $\frac{kgBOD}{kgMLVSS\ d}$	Volumetric loading rate $\frac{kgBOD}{m^3\ d}$	MLSS $\frac{kg}{m^3}$	HRT [h]	Solid Retention Time [d]	Air requirement $\frac{Nm^3}{kgBOD_{removed}}$	Recycle ratio [%]	BOD_5 removal efficiency [%]
Conventional (complete mix)	Air diffusion or Mechanical aerators	CSTR	0.2 – 0.6	0.8 – 1.9	3 - 6	3 - 5	5 - 15	35	25 – 100	85 – 95
Conventional (plug flow)	Air diffusion or Mechanical aerators	Plug flow	0.2 – 0.4	0.3 – 0.6	1.5 - 3	4 - 8	5 - 15	50 - 60	25 – 50	85 – 95
Extended Aeration	Air diffusion or Mechanical aerators	Plug flow or CSTR	0.05 – 0.15	0.15 – 0.4	3 – 6	18 – 36	20 – 30	75 – 110	75 – 150	75 – 95
Contact stabilization	Air diffusion or Mechanical aerators	Plug flow	0.2 – 0.6	0.9 – 1.2	1. – 3 4 - 10	0.5 – 1 3 - 6	5 - 15	50	25 - 100	80 – 90
High rate aeration	Mechanical aerators	Plug flow or CSTR	0.4 – 1.5	1.2 – 2.4	4 – 10	1 - 3	5 - 10		100 - 500	75 – 90
Step feed	Air diffusion	Plug flow	0.2 – 0.4	0.6 – 0.9	2 – 3.5	3 - 5	5 - 15	30 - 45	25 - 75	85 – 95
High purity oxygen	Mechanical aerators	CSTR	0.25 – 1	1.6 – 4	6 – 8	1 - 3	8 - 20		25 – 50	85 – 95

Tab 3.4.2 Aeration basin operation sheet

Month: ……..; Year: ……. ; Operator: ……………………….; Item nr: ……………….

Day	Hour	Operational parameters									Treatment efficiency							Notes
		Temperature (ML)	IIN flow rate	Recycle flow rate	Waste sludge flow rate	DO	MLVSS	HRT	SRT	F/M	Volumetric loading rate	Recycle ratio	IN	OUT	IN	OUT		
		[°C]	[$m^3 d^{-1}$]			[$g\ m^{-3}$]	[$kg\ m^{-3}$]	[h]	[d]	$\frac{kgBOD}{kgMLVSS\ d}$	$\frac{kgBOD}{m^3\ d}$	[%]	[$g\ m^{-3}$]		[$g\ m^{-3}$]			
1																		
2																		
3																		
31																		
Monthly mean																		

3.4.1 Activated Sludge troubles and remedial actions

3.4.2.1 Sludge Bulking (filamentous microrganisms)

<u>Symptoms</u>

- High TSS content in the secondary clarifier effluent
- Filamentous microorganisms in mixed liquor

<u>Main causes</u>

- Low nutrient concentration in the incoming wastewater
- Toxic compounds in the incoming wastewater
- Wide pH and temperature oscillations
- High organic loading rate
- Insufficient aeration

<u>Investigations and analyses</u>

- Measure the Sludge Volume Index (SVI)
- Microscopic observations
- Check the C:N:P ratio or BOD_5:N:P ratio
- Measure temperature, pH and DO (in different sections of the aeration tank)
- Check F/M, volumetric organic loading rate, SRT
- Check toxic compounds in the incoming wastewater

<u>Remedial actions</u>
- Chlorine or oxygen peroxide dosage in the return sludge line (5 – 15 g Cl kg^{-1}SS d^{-1})
- Inorganic coagulants (cake, ferric chloride, etc.) dosage
- Increase SRT
- PH and DO
- BOD_5:N:P ratio correction in the incoming wastewater

3.4.2.2 Foaming

<u>Symptoms</u>
- Scum presence in the aeration basin

<u>Main causes</u>
- High content of foaming agents and/or oils and greases in the incoming wastewater

<u>Investigations and analyses</u>
- Evaluate the presence of *Nocardia* in the mixed liquor and in the foam
- Evaluate oil and grease in the influent wastewater
- Evaluate temperature oscillation in the aeration basin

<u>Remedial actions</u>
- Foam removal through water sprinkling
- Chlorine dosage

3.4.2.3 Air diffusers clogging

<u>Symptoms</u>
- Air flow rate reduction
- Increased headloss in the air line

<u>Main causes</u>
- High dust content in the air
- Oil content in the air due to air compressor faulty operation
- Rust presence in the air pipeline due to the condensing moisture
- Organic material growth or solids precipitation over air diffusers
- Solid deposition over air diffusers during aeration interruption

<u>Investigations and analyses</u>
- Check the dust, rust and oil content in the air flowing to the diffusers
- Check breaks presence in the air pipeline through which mixed liquor could enter during aeration interruption

Remedial actions
- Keep air compressors as much regularly operated as possible
- Check regularly the air filtration system
- Install oil trap on the air compressor
- Periodical maintenance of the air pipeline
- Enhance degritting and screening

3.4.2.4 Low DO value in the aeration basin

Symptoms
- Efficiency reduction
- DO reduction in the aeration basin; and temporary bulking
- Mixed liquor dark colour

Main causes
- Insufficient aeration
- Wide oscillation of the organic loading rate

Investigations and analyses
- Measure DO concentration in the aeration basin specially in the dead zones
- Measure wastewater flow rate and organic concentration during peak time

Remedial actions
- Increase the volume of the aeration basin (raising the water level)
- Increase the aeration

3.5 Anaerobic Treatment

Activated sludge treatment step takes place into aeration tanks, whose footprint shape has to be defined according to the aeration devices to be installed.

Wastewater load and temperature affect the feasibility of wastewater anaerobic treatment. Generally, COD concentration higher than 1550–2000 g m^{-3} and reactor temperature in the range of 25-35°C are needed.
The principal advantages of anaerobic treatment can be summarised as in the following:

- Low running costs, mainly due to the lack of any aeration system
- High methane rich biogas production
- Low sludge production
- Less nutrients required by the process

The most diffused types of anaerobic reactor are:

- Anaerobic contact process;
- UASB (Upflow Anaerobic Sludge Blanket)
- Upflow and Downflow attached growth processes
- Fluidized Bed Reactor

Basing on the OLR (Organic Loading Rate) the anaerobic processes can be classified in low rate (up to 5 kg COD m^{-3} d^{-1}) and high rate reactors.
Start-up time to develop biomass inventory is essential, therefore seed sludge has to be chosen very carefully.
The anaerobic process is very sensitive and the main instability, at full scale plants, are due to wide variations of temperature, flow rate and organic loading rate.

The main process control parameters are listed below:

- Chemical and biological wastewater characteristics
- Temperature
- Organic Loading Rate
- Hydraulic Retention Time
- Biogas production

As a general advice, the type of anaerobic process to be applied has to be defined very carefully according to the specific site characteristics, taking into account all the factors that could affect the process, evaluating their average values and their variability. Process monitoring and control have to be guaranteed in order to prevent and avoid operational problems.

3.6 Lagoons

Suspended growth lagoons are shallow earthen basins varying in depth from 1 to 6m. The aerated lagoons depth ranges usually between 1.8 and 6m, mixing and aeration is provided through the use of slow-speed surface aerators mounted on floats. Non aerated lagoons can be classified in aerobic, facultative and anaerobic lagoons, depending on the main environmental conditions: biological conversion is carried out in aerobic and/or anaerobic conditions.

The aerobic lagoons depth usually ranges between 1 and 1.5m in order to guarantee sufficient oxygen concentration in the water. In facultative lagoons three different zones can be observed: superficial aerobic zone, anaerobic bottom zone (where settleable solids accumulate) and a facultative zone where biological processes are carried out by facultative bacteria. The anaerobic lagoon are deeper than the others and the main biological conversion is essentially anaerobic.

3.6.1 Lagoons troubles and remedial actions

3.6.1.1 Foul smell emanation due to high organic load

Symptoms
- Foul smell emanation from the lagoon
- pH and DO (Dissolved Oxygen) reduction trend

Main causes
- Biological oxygen demand higher than the available oxygen

Investigations and analyses
- Measure the pH and DO

Remedial actions
- Reduce the organic loading rate
- Install suitable aerator, converting the lagoon in an aerated lagoon

3.6.1.2 Abnormal mosquitoes growth

Symptoms
- Mosquitoes presence

Main causes
- Presence of stagnant water and/or dead zones in the lagoon where a abnormal common weed growth is observed

Remedial actions
- Remove common weed
- Use of insecticides (in this case the interruption of the incoming wastewater for 1 –2 days is needed)

Typical operational data for different lagoon are presented in table 3.6.1.

Tab. 3.6.1 Typical operational data for lagoon type

Lagoon		Depth [m]	OLR [kg BOD_5 ha^{-1} d^{-1}]	HRT [d]	BOD_5 removal [%]
Aerated		1.5 – 6		3 – 10	80 – 95
Non aerated	Aerobic	1 –1.5	40 – 120	10 – 40	80 – 95
	Facultative	1 – 2	20 – 80	7 – 30	80 – 95
	Anaerobic	2.5 - 5		20 - 50	50 - 85

In table 3.6.2 a typical lagoon operation sheet is reported; the reporting frequency depends on the WWTP size; details on routine inspections, lubrication and adjustment, performed by the operator, should be reported as well.

Tab 3.6.2 Lagoon operation sheet

Month: ……..; Year: ……. ; Operator: ……………………….; Item nr: ……………….

Day	Hour	pH		Temperature [°C]	Flow rate [m^3 d^{-1}]	DO [g m^{-3}]	HRT [d]	OLR [kg BOD_5 ha^{-1} d^{-1}]	TSS		BOD5			Notes
		in	out						In [g m^{-3}]	Out [g m^{-3}]	In [g m^{-3}]	Out [g m^{-3}]	Removal [%]	
1														
2														
31														
Monthly mean														

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