TABLE OF CONTENT

LIST OF TABLE

LIST OF FIGURE

INTRODUCTION

Scope

This design guideline covers the basic elements of Waste Water Treatment in sufficient detail to allow an engineer to develop and implement a waste water treatment system.

Sewage or waste water is a mixture of domestic and industrial wastes. It is more than 99% water, but the remainder contains some ions, suspended solids and harmful bacteria that must be removed before the water is released into the sea. Wastewater treatment is a process to convert wastewater which is water no longer needed or suitable for its most recent use - into an effluent that can be either returned to the water cycle with minimal environmental issues or reused

The first stage of waste water treatment takes place in the preliminary treatment plant where material such as oils, fats, grease, grit, rags and large solids are removed. Primary settlement is sometimes used prior to biological treatment. Radial or horizontal flow tanks are normally employed to reduce the velocity of flow of the waste water such that a proportion of suspended matter settles out.

Biological treatment of waste waters takes place in fixed media or suspended growth reactors using activated sludge, biofiltration, rotating biological contactors, constructed wetlands or variants of these processes. Secondary settlement separates the sludge solids from the outflow of the biological stage. Tertiary treatment refers to processes which are used to further reduce parameter values below the standards set out in national regulations. The term is often used in reference to nutrient removal.

The waste water treatment may be influenced by factors, including process requirements, economics and safety. In this guideline, there are tables that assist in making these factored calculations from the various reference sources. Include in this guideline is a calculation spreadsheet for the engineering design. All the important parameters use in the guideline are explained in the definition section which helps the reader understand the meaning of the parameters or the terms utilized.

General Design Consideration

Water is necessary for life on earth. In nature it comes in three aggregate forms (snow / ice, liquid, vapor / steam). The majority of particle transport is carried out through water. In water many particles become dissolved. Water also has a great capacity to take on heat. A by-product of human usage is that the water then becomes polluted with contaminants. Water is used with many industrial processes and wastewater is produced. The amount and composition of wastewater are strongly related to the type of industry. Even the degree of internal recirculation and water saving has a large influence. If the industrial treatment is adequate, it may be allowed directly discharge to the surface water.

Water Basics

- H2O
- dipole
- solid, liquid, gas (0°C, 100°C)
- density (1,000 kg/m^3)
- heat: specific heat 4.18 kj/(kg ˚C); heat of evaporation/enthalpy of vaporization 2,250 kj/kg
- viscosity: 1.0 mPa.s with 20˚
- contaminants: dissolved (< 10 nm), colloidal (10 nm^{-1} μm), suspended solids (> 1 μm)
- water as a solvent: gases (Henry's Law), liquids (miscibility)
- ionization: ions, acids, bases
- oxidation-reduction
- biology: bacteria, pathogens, substrate, nutrients

Wastewater treatment is a process to convert wastewater - which is water no longer needed or suitable for its most recent use - into an effluent that can be either returned to the water cycle with minimal environmental issues or reused. The latter is called water reclamation and implies avoidance of disposal by use of treated wastewater effluent for various purposes. Treatment means removing impurities from water being treated; and some methods of treatment are applicable to both water and wastewater.

The physical infrastructure used for wastewater treatment is called a "wastewater treatment plant" (WWTP). Wastewater that is treated in a municipal wastewater treatment plant (WWTP) or sewage treatment plant (STP) can have various sources. The influent of the typical WWTP consists of mostly wastewater from households and businesses (urban/municipal wastewater, or “sewage”).

The treatment of wastewater belongs to the overarching field of Public Works - Environmental, with the management of human waste, solid waste, sewage treatment, storm-water (drainage) management, and water treatment. By-products from wastewater treatment plants, such as screenings, grit and sewage sludge may also be treated in a wastewater treatment plant. If the wastewater is predominantly from municipal sources (households and small industries) it is called sewage and its treatment is called sewage treatment.

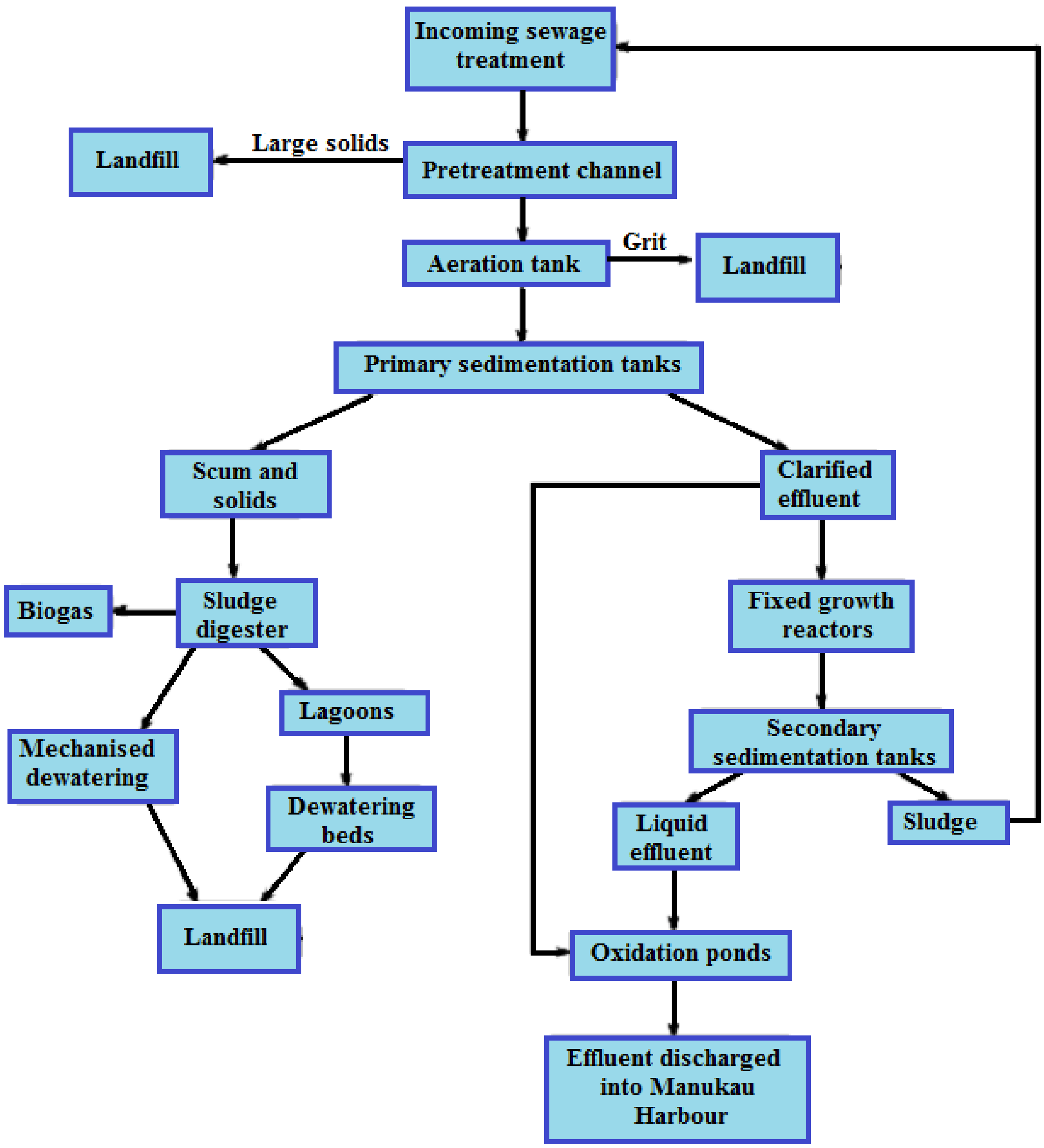

Figure 1: Sewage treatment flow diagram

Wastewater

The influent wastewater composition varies depending on the type of industry and the management. The contaminants transported by these wastewater flows determine the (biological) capacity of the WWTP required to treat it. The most important components in urban wastewater are depicted in table 1

Table1. The most important components in urban wastewater

Chemical oxygen demand	COD	g O_2/m^3
Biochemical oxygen demand	BOD_5	g O_2/m^3
Total nitrogen	N_{total}	g N/m^3
$N\text{-}NH_4$ (ammonium nitrogen)	NH_4	g N/m^3
Nitrite	NO_2	g N/m^3
Nitrate	NO_3	g N/m^3
Kjeldahl nitrogen	N-Kj	g N/m^3
Total phosphorus	P_{total}	g P/m^3
Ortho-phosphate	P_{ortho}	g P/m^3
Dry solids	Ds	g ds/m^3
Total suspended solids	TSS	g ds/m^3
Chloride	Cl^-	g $/m^3$
Sulfide	S^{2-}	g $/m^3$
Sulphate	SO_4^{2-}	g $/m^3$

1. Solid

The size of compounds in wastewater differ greatly. Visible particles or un-dissolved matter are 0.1μm and larger. Compounds with a particle size between 1 and 100 nm are called colloidal particles. Dissolved solids measure from 1 nm or smaller. The un-dissolved solids can be separated from the dissolved solids through filtration; the remaining material from and on top of the filter, after having dried and weighed the filtration solids in g/l or mg/l (undissolved solids), can be determined. From the filtrate after evaporating comes the content of dissolved solids.

2. Biodegradable Organic Substances

Organic compounds are formed mainly from carbon and hydrogen, bonded with other elements. Carbons typically present in domestic wastewater include:

- carbohydrates generally to be seen as $(CH_2O)n$
- fats (esters of glycerin and fatty acids);
- proteins (compounds made up of C and H and also N and sometimes P and S);
- urea, that gets excreted through urine: $CO(NH_2)_2$.
- Phenols detergents and pesticides

Explicit inorganic substances in wastewater are salt, sand, loam and ash, and cannot be removed through biodegradation. Organic compounds within wastewater for the most part are biodegradable, thus in the presence of aerobic microorganisms these biodegradable compounds can be broken down, consuming dissolved oxygen in the process.

3. Nutrients

Nitrogen and phosphorus are the two most common nutrients monitored in wastewater effluent due to their roles as limiting nutrients in eutrophication of marine and freshwater environments respectively. Carbon, nitrogen, and phosphorus are essential to living organisms and are the chief nutrients present in natural water. Large amounts of these nutrients are also present in sewage, certain industrial wastes, and drainage from fertilized land. Conventional secondary biological treatment processes do not remove the phosphorus and nitrogen to any substantial extent -- in fact, they may convert the organic forms of these substances into mineral form, making them more usable by plant life.

When an excess of these nutrients over-stimulates the growth of water plants, the result causes unsightly conditions, interferes with drinking water treatment processes, and causes unpleasant and disagreeable tastes and odors in drinking water. The release of large amounts of nutrients, primarily phosphorus but occasionally nitrogen, causes nutrient enrichment which results in excessive growth of algae. Uncontrolled algae growth blocks out sunlight and chokes aquatic plants and animals by depleting dissolved oxygen in the water at night. The release of nutrients in quantities that exceed the affected water body's ability to assimilate them results in a condition called eutrophication or cultural enrichment.

4. Pathogens

For the bacteriological/ assessment of water in terms of whether it has been contaminated with feces is often used for checking the presence of the coli-bacteria. 106 - 108 intestinal bacteria are found in 100 ml. domestic wastewater. A large amount of that in general consists of innocent coli-bacteria. In faces bacteria can also be present that cause intestinal diseases such as typhoid fever, paratyphoid fever (salmonellosis) in various forms and bacillary dysentery as well as viruses, of which can be the causers of infantile paralysis, jaundice, and worm eggs, for example lint worms and round worms and small intestinal worms. Moreover, contact with wastewater can bring about skin reactions.

Infectious micro-organisms, or pathogens, may be carried into surface and groundwater by sewage from cities and institutions, by certain kinds of industrial wastes, such as tanning and meat packing plants, and by the contamination of storm runoff with animal wastes from pets, livestock and wild animals, such as geese or deer. Humans may come in contact with these pathogens either by drinking contaminated water or through swimming, fishing, or other contact activities. Modern disinfection techniques have greatly reduced the danger of waterborne disease.

Many industries use large volumes of water in their manufacturing operations. Industrial Waste Water Treatment Systems treat wastewater from an industrial or manufacturing process such as a cooling tower, food or animal processing plant or any type of manufacturing process that generates wastewater. The Pulp and Paper, Steel, Refining, and Chemical industries account for more than 90% of the water used by industries in North America. The treatment process and equipment is specifically directed to control or remove certain organic or chemical compounds.

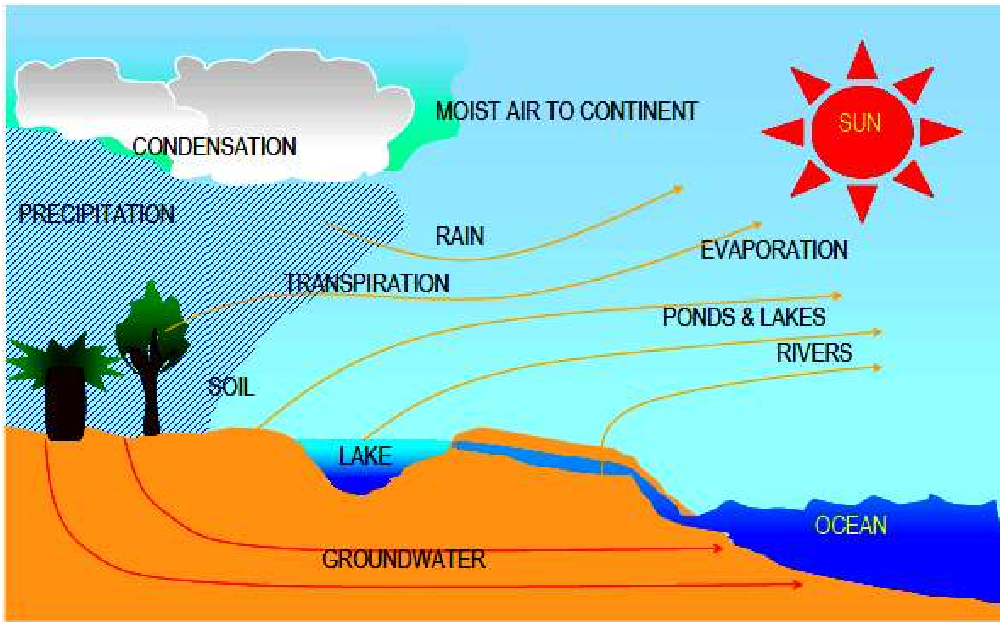

Figure 2: The water cycle

The amount of organic material that can be discharged safely is defined by the effect of the material on the dissolved oxygen level in the water. Organisms in the water use the organic matter as a food source. In a biochemical reaction, dissolved oxygen is consumed, as the end product of water and carbon dioxide are formed. Atmospheric oxygen can replenish the dissolved oxygen consumption to exceed this re-supply; the dissolved oxygen level drops, leading to the death of fish and other aquatic life.

Under extreme conditions, when the dissolved oxygen concentration reaches zero, the water may turn black and produce odors. Organic compounds are normally measured as chemical oxygen demand (COD) and biochemical oxygen demand (BOD).

Industrial Waste Water Considerations include:

1. Volume of daily flow
2. All biological and chemical characteristics of the wastewater,
3. Including biodegradability, toxic material content and any material covered by specific environmental regulations
4. Regulations of the local health department and federal or state Environmental Protection Agency

The Waste Water Treatment System can be broken down into distinct components.

1. Pretreatment Units
2. Primary Treatment
3. Secondary Treatment
4. Tertiary Treatment
5. Sludge Handing (thickening and denaturing)
6. Sludge Disposal

In most situations the required wastewater treatment is carried out at wastewater treatment plants. A sewage treatment plant must:

- treat the wastewater to such an extent that meets the effluent requirements.
- be able to handle the inherent variations that are in the wastewater as well as variations in the amount of wastewater.
- be robustly constructed;
- be able to treat the wastewater at a minimum annual cost;
- cause minimum amount of disturbance to the surrounding areas.

Basic Wastewater Treatment Processes

1. **Physical**

   Physical processes were some of the earliest methods to remove solids from wastewater, usually by passing wastewater through screens to remove debris and solids. In addition, solids that are heavier than water will settle out from wastewater by gravity. Particles with entrapped air float to the top of water and can also be removed. These physical processes are employed in many modern wastewater treatment facilities today.

2. **Biological**

   In nature, bacteria and other small organisms in water consume organic matter in sewage, turning it into new bacterial cells, carbon dioxide, and other by-products. The bacteria normally present in water must have oxygen to do their part in breaking down the sewage. In the 1920s, scientists observed that these natural processes could be contained and accelerated in systems to remove organic material from wastewater. With the addition of oxygen to wastewater, masses of microorganisms grew and rapidly metabolized organic pollutants. Any excess microbiological growth could be removed from the wastewater by physical processes.

3. **Chemical**

   Chemicals can be used to create changes in pollutants that increase the removal of these new forms by physical processes. Simple chemicals such as alum, lime or iron salts can be added to wastewater to cause certain pollutants, such as phosphorus, to flock or bunch together into large, heavier masses which can be removed faster through physical processes. Over the past 30 years, the chemical industry has developed synthetic inert chemicals know as polymers to further improve the physical separation step in wastewater treatment. Polymers are often used at the later stages of treatment to improve the settling of excess microbiological growth or bio-solids.

Processes Utilized

Pre-treatment is dedicated to removing coarse material and sand; these particles can cause difficulties further along in the treatment process (blockages, damage to the components, etc.) if they are not removed. Subsequently the settle-able substances are separated (mechanical treatment) which is referred to as primary treatment or clarification, however this step can also be omitted in some treatment configurations.

After this follows secondary treatment which encompasses the removal of the dissolved and suspended organic contaminants through a biological process; nitrogen and phosphorus compounds can also be removed in the secondary process. Then the biological (or activated) solids produced by the secondary process are separated in a secondary clarifier.

Next the effluent is either discharged into the surface water or an extended or physical-chemical purification process can be deployed as the last phase prior to discharge. The extended treatment often focuses less on the oxygen demanding substances, but more on other components (e.g. micro pollutants, heavy metals, pathogens, etc.). These processes include active-carbon treatment, filtration, chlorination, membrane filtration, ion exchangers and chemical precipitations. In practice this rarely happens.

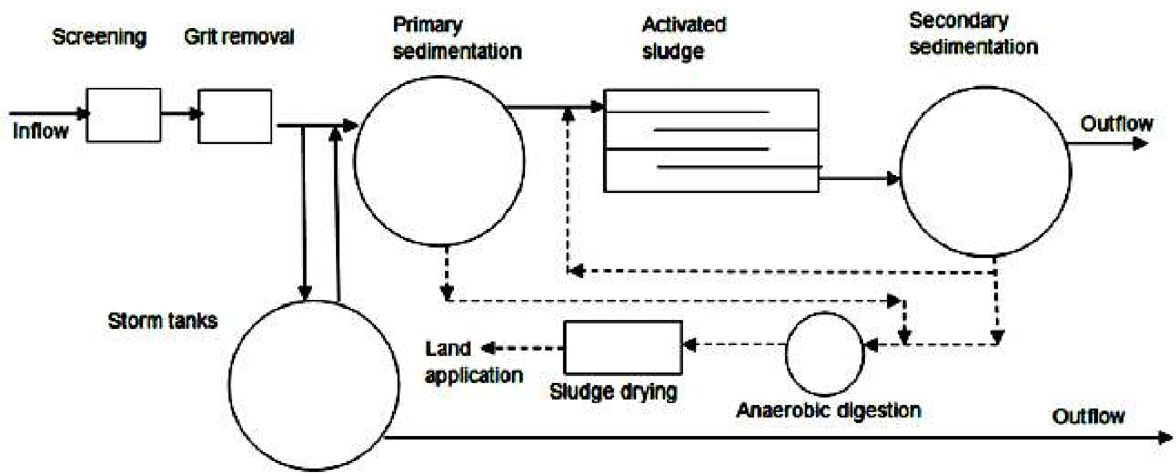

Figure 3: Waste water treatment plant overview (Tebutt, 1998)

Pretreatment Units

As wastewater enters a treatment facility, it typically flows through a step called preliminary treatment. A screen removes large floating objects, such as rags, cans, bottles and sticks that may clog pumps, small pipes, and downstream processes. The screens vary from coarse to fine and are constructed with parallel steel or iron bars with openings of about half an inch, while others may be made from mesh screen with much smaller openings.

Screens are generally placed in a chamber or channel and inclined towards the flow of the wastewater. The inclined screen allows debris to be caught on the upstream surface of the screen, and allows access for manual or mechanical cleaning. Some plants use devices known as comminutors or barminutors which combine the functions of a screen and a grinder. These devices catch and then cut or shred the heavy solid and floating material. In the process, the pulverized matter remains in the wastewater flow to be removed later in a primary settling tank.

After the wastewater has been screened, it may flow into a grit chamber where sand, grit, cinders, and small stones settle to the bottom. Removing the grit and gravel that washes off streets or land during storms is very important, especially in cities with combined sewer systems. Large amounts of grit and sand entering a treatment plant can cause serious operating problems, such as excessive wear of pumps and other equipment, clogging of aeration devices, or taking up capacity in tanks that is needed for treatment. In some plants, another finer screen is placed after the grit chamber to remove any additional material that might damage equipment or interfere with later processes. The grit and screenings removed by these processes must be periodically collected and trucked to a landfill for disposal or are incinerated.

Phase separation transfers impurities into a non-aqueous phase. Phase separation may occur at intermediate points in a treatment sequence to remove solids generated during oxidation or polishing. Grease and oil may be recovered for fuel or saponification. Solids often require dewatering of sludge in a wastewater treatment plant. Disposal options for dried solids vary with the type and concentration of impurities removed from water.

Table 2: Process to removed contaminants

Contaminants	Effects on discharge	Processes
coarse particles and settle able solids	sludge sedimentation decomposition oxygen depletion	Sieves sediments
Non settle able, biodegradable substances	oxygen depletion	biological treatment
ammonia (Kjeldahl-N)	oxygen depletion toxic for fish negative for drinking water preparation eutrophication	biological nitrification chemical-physical stripping
Un-dissolved (suspended particles)	oxygen depletion eutrophication	micro-sieves filtration
inorganic nutrients - nitrate - phosphate	Eutrophication influencing oxygen content negative for drinking water preparation	biological denitrification chemical precipitation biological removal
dissolved, biological resistant organic particles	Poisoning destroying biotope accumulation in the food chain negative for drinking water preparation	activated-carbon absorption chemical oxidation
dissolved inorganic particles	Poisoning destroying biotope accumulation in the food chain negative for drinking water preparation	ion exchangers electro dialysis reversed osmosis distillation
pathogenic organisms	worsening hygienic quality	disinfection

1. Sedimentation - Gravity Separation

With the screening completed and the grit removed, wastewater still contains dissolved organic and inorganic constituents along with suspended solids. The suspended solids consist of minute particles of matter that can be removed from the wastewater with further treatment such as sedimentation or gravity settling, chemical coagulation, or filtration. Pollutants that are dissolved or are very fine and remain suspended in the wastewater are not removed effectively by gravity settling.

Sedimentation is the separation from water of suspended particles that are heavier than water by gravitational settling. The purpose of sedimentation is 1) clarification - to produce clean water, which can be used, recycled or further treated and 2) consolidation - to produce concentrated solids that can be more easily handled and treated.

Solids and non-polar liquids may be removed from wastewater by gravity when density differences are sufficient to overcome dispersion by turbulence. Gravity separation of solids is the primary treatment of sewage, where the unit process is called "primary settling tanks" or "primary sedimentation tanks". It is also widely used for the treatment of other wastewaters. Solids that are heavier than water will accumulate at the bottom of quiescent settling basins. More complex clarifiers also have skimmers to simultaneously remove floating grease like soap scum and solids like feathers or wood chips. Containers like the API oil-water separator are specifically designed to separate non-polar liquids.

When the wastewater enters a sedimentation tank, it slows down and the suspended solids gradually sink to the bottom. This mass of solids is called primary sludge. Various methods have been devised to remove primary sludge from the tanks.

Most waste treatment system employ a gravity separation step for suspended particle or oil removal. The settling rate of a particle is defined in terms of “free” verses “hindered” settling. A free settling particle’s motion is not affected by that of other particles, the vessel’s wall, or turbulent currents. A particle has a hindered settling rate if there is any interference from these effects.

Table 3: Effect of Particle Size on Settling

Unit	Size (microns)	Time to fall 1 meter	Settling (m/h)
Gravel	10,000	1 sec	3600
Sand Course	1,000	10 sec	360
Sand Fine	100	125 sec	28
Silt	10	108 min	0.5
Bacteria	1	180 hr	
Colloidal matter	0.1	2 years	
Color Particles	0.001	200 years	

Gravity settling is employed primarily for removal of inorganic suspended solids, such as grit and sand. The equipment employed for gravity separation for waste treatment is normally either a rectangular basin with moving bottom scrapers for solids removal or a circular tank with a rotating bottom scraper.

Rectangular tanks are normally sized to decrease horizontal fluid velocity to approximately 1 foot per minute. Their lengths are three to five time their width and their depths are three to eight feet. Circular clarifiers are ordinarily sized according to the surface area, because velocity must be reduced below the design particle's terminal velocity. The typical design provides a rise rate of 600-800 gpd/sqft.

Primary Treatment

The initial stage in the treatment of domestic wastewater is known as primary treatment. With the screening completed and the grit removed, wastewater still contains dissolved organic and inorganic constituents along with suspended solids. The suspended solids consist of minute particles of matter that can be removed from the wastewater with further treatment such as sedimentation or gravity settling, chemical coagulation, or filtration. Pollutants that are dissolved or are very fine and remain suspended in the wastewater are not removed effectively by gravity settling. When the wastewater enters a sedimentation tank, it slows down and the suspended solids gradually sink to the bottom. This mass of solids is called primary sludge. Various methods have been devised to remove primary sludge from the tanks. Newer plants have some type of mechanical equipment to remove the settled solids from sedimentation tanks. Some plants remove solids continuously while others do so at intervals.

1. Air Flotation

Where the density differential is not sufficient to separate oil and oil-wetted solids, air flotation may be used to enhance oil removal. In this method, air bubbles are attached to the contaminant particles and thus the apparent density difference between the particles is increased.

Dissolved air flotation (DAF) is a method of introducing air to a side stream or recycle stream at elevated pressures in order to create a super saturated stream. When this stream is introduced into the waste stream, the pressure is reduced to atmospheric, and the air is release as small bubbles. These bubbles attach to contaminants in the waste, decreasing their effective density and aiding in their separation. The most important operation parameters for contaminate removal by dissolved air flotation are;

- Air pressure
- Recycle or slip stream flow rate
- Influent total suspended solids (TSS) including oil and grease
- Bubble size
- Dispersion

As in gravity settling, air flotation units are designed for a surface-loading rate that is a function of the waste flow and rise velocity of the contaminants floated by air bubbles. The retention time is a function of the tank depth. DAF units can be rectangular in design but are usually circular, resembling a primary clarifier or thickener. They are often single stage units.

Induced Air Flotation (IAF) is another method of decreasing particle density by attaching air bubbles to the particles, however the method of generating the air bubble differs. A mechanical action is employed to create the air bubbles and their contact with the waste contaminants. The most common methods use high-speed agitators or recycle a slipstream through venturi nozzles to entrain air into the wastewater. In contrast to DAF units, IAF units are usually rectangular and incorporate four or more air flotation stages in series. The retention time per stage is significantly less that in DAF circular tanks.

As in gravity settling, the diameter of the particle plays an important role in separation. Polyelectrolytes may be used to increase effective particle diameters. Polymers are also used to destabilize oil / water emulsions, thereby allowing the free oil to be separated from the water. Polymers do this by charge neutralization, which destabilizes an oil globule surface and allows it to contact other oil globules and air bubbles. Emulsion breakers, surfactants, or surface-active agents are also used in air flotation to destabilize emulsions and increase the effectiveness of the air bubbles.

2. Filtration

Filtration is employed in waste treatment whenever suspended solids must be removed. In practice, filtration is most often used to polish wastewater following treatment. In primary waste treatment, filters are often employed to remove oil and suspended solids prior to biological treatment. More commonly, filters are used following biological treatment prior to final discharge or reuse. Filtration is also widely used as a tertiary treatment for suspended solids removal. The fundamental requirement is that the suspended particles are of sufficient size or capable of being increased in size by flocculation. In cases when it is not possible to flocculate such particles, more advanced techniques such as ultra-filtration is more practical.

Some of the advantages of filtration are as follows:

a. Simple to operate and easy to control
b. Can be used for almost any type of free-flowing liquid stream containing suspended solid particles
c. Relatively cost competitive with regard to sludge dewatering processes
d. Lower energy consumption as compared to others
e. Can be integrated easily with other treatment trains

f. Great potential for recovery as the process will not chemically change the characteristics of the materials treated.

Some of the disadvantages, among others are:

a. Not capable of producing a high purity effluent as both the liquid product and dewatered sludge still contain a certain fraction of the liquid and solid phase
b. Not capable of separating chemical components especially when they are present in the same phase.
c. Not capable of destroying or chemically changing the toxicity of materials
d. Will produce a liquid waste stream that requires further treatment prior to disposal.

Secondary Treatment

Secondary sewage treatment, which is predominantly biological, is designed to remove most of this organic matter and reduce the BOD. In this process, the sewage undergoes strong aeration to encourage the growth of aerobic bacteria and other microorganisms that oxidize the dissolved organic matter to carbon dioxide and water.

After the wastewater has been through Primary Treatment processes, it flows into the next stage of treatment called secondary. Secondary treatment processes can remove up to 90 percent of the organic matter in wastewater by using biological treatment processes. The two most common conventional methods used to achieve secondary treatment are attached growth processes and suspended growth processes.

The Secondary Treatment consists of at least two types of systems. The first is Fixed Film / Media System and the second is Suspended Growth Systems. The attached growth (also called fixed film') processes, wherein the cells are attached onto a surface as a biofilm and the water is passed over the surface. The Fixed Film / Media Biological Oxidation System has a media in which the Biological Film is attached to a Media.

The Waste Water is slowly passed through the Media and the Biological Film degrades the organics to non-organic products. The fixed film system includes Trickling filters, Rotating Biological Contactor (RBC), etc. The suspended growth processes, wherein the bacterial cells are suspended in the water column in a tank. The Suspended Growth Biological Oxidation System includes Stabilization Ponds, Single Pass Aerated Lagoons and Activated Sludge Systems

1. Biological Oxidation

One of the most common ways to convert soluble organic matter to insoluble matter is through biological oxidation. Soluble organics metabolized by bacteria are converted to carbon dioxide and bacterial floc, which can be settled from solution.

Secondary treatment by biochemical oxidation of dissolved and colloidal organic compounds is widely used in sewage treatment and is applicable to some agricultural and industrial wastewaters. Biological oxidation will preferentially remove organic compounds useful as a food supply for the treatment ecosystem. Concentration of some less digestable compounds may be reduced by co-metabolism. Removal efficiency is limited by the minimum food concentration required to sustain the treatment ecosystem

The biodegradable contaminants in water are usually measured in terms of biochemical oxygen demand (BOD). BOD is actually a measure of the oxygen consumed by microorganisms as they assimilate organics. Bacteria metabolize oxygen along with certain nutrients and trace metals to from cellular matter, energy carbon dioxide, water and more bacteria. The purity of the water depends on minimizing the amount of organic compounds that remain after secondary treatment. Factors that affect biological oxidation are shown in Table 4.

Table 4: Factors that affect biological oxidation

Food, BOD	To maintain control with efficient BOD removal, the proper amount of food must be supplied
Dissolved Oxygen	Insufficient oxygen levels inhibit BOD removal
pH, toxicants	With time, bacteria adapt to change in conditions. Rapid changes in pH or type of waste organic inhibit the process
Time	The degree of degradations varies with time
Nutrients	Bacteria require trace amounts of nitrogen and phosphorus for cell maintenance.
Temperature	Low Temperature result in slow reaction rates, higher temperature may kill many strains of bacteria

2. Fixed Film / Media Systems

Fixed Film / Media Oxidation passed influent wastewater across a substructure laden with fixed biomass. Fixed media allow a biological layer to grow on a substructure continually exposed to raw wastewater. As the layer grows in thickness oxygen transfer to the inter-most layers is impeded. Eventually, some of the layer is removed. This phenomenon is called sloughing. In a continuous process this material is carried to a sedimentation stage, where it is removed.

Media plugging and lack of oxygen transfer are the primary difficulties encountered with fixed media designs. Plugging problems can be alleviated by increase wastewater shear. This is normally accomplished by recycling a portion of the wastewater. The graphical representation of bio-film formations in the fixed film/media system is shown in Figure 4.

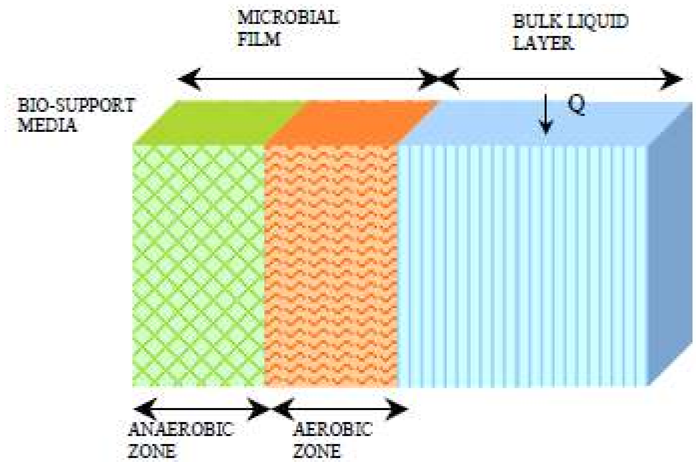

Figure 4: bio-film formations in the fixed film/media system

3. Activated Sludge Systems

Activated sludge system is a biological process that is characterized by the suspension of aerobic microorganisms being maintained in a relatively homogenous state by the mixing or turbulence induced from the aeration process.

The microorganisms oxidize the soluble and colloidal organics in the presence of molecular oxygen. In the oxidation process, a part of the organic material is transformed into new cells that subsequently undergo auto-oxidation in the aeration basin. In the conventional activated sludge process, the typical hydraulic retention time (HRT) is in the range of 6 to 10 hours, and the volumetric loading rate (VLR) of the reactor is in the range of 0.32 to 0.64 kg BOD /m^3 day.

In the aeration tanks of an activated sludge system**,** air or pure oxygen is passed through the effluent from primary treatment. The name is derived from the practice of adding some of the sludge from a previous batch to the incoming sewage. This inoculum is termed *activated sludge* because it contains large numbers of sewage-metabolizing microbes. The activity of these aerobic microorganisms oxidizes much of the sewage organic matter into carbon dioxide and water. Especially important members of this microbial community are species of *Zoogloea* bacteria, which form bacteria containing masses in the aeration tanks called floc, or *sludge granules.*

In the process, Soluble organic matter in the sewage is incorporated into the floc and its microorganisms. The flocs generated from the oxidation process are separated in a clarifier and partly recycled into the aeration basin with some removed for disposal off site or further treatment. The supernatant overflows from the clarifiers as final discharge.

The process has been widely used throughout the world as one of the most proven method to treat, not only sewages but also highly toxic industrial wastewaters. Since its invention, the process has been modified to improve its efficiency and reduce the capital and operation costs.

The advantages of the activated sludge process are as follows:

- Requires limited space – HRT is 3 to 36 hour range
- MLSS is in the range of 1500 to 10,000 mg/l
- Reliable operator control capability
- Can handle shock loads better with less recovery time required
- Can handle high loaded waste streams
- Excellent solids removal capability

The disadvantages, among others, are as follows:

- Requires highly trained operators
- Requires substantial monitoring
- Requires high operation and maintenance costs
- Sensitive to toxic discharges or load fluctuations
- Generates waste sludge products that are difficult to dewater

The control of contaminate oxidation at high BOD loading requires a bacteria population that is equal to the level of food. The need is the basis for the activated sludge process. In the activated sludge process, reactants, food, and microorganism are mixed in a controlled environment to optimize BOD removal. The process incorporates the return of concentrated microorganisms to the influent waste.

When bacteria are separated from wastewater leaving an aeration basin and reintroduced to the influent, they continue to thrive. The re-circulated bacteria continue to oxide wastewater contaminates, and if present in sufficient quaintly, produce a relatively low BOD effluent water. Because the activated sludge process incorporates the return of concentrated microorganisms, it must include a process for microorganism concentration and removal. This process includes an aeration stage and a sedimentation stage.

Types of Activated Sludge Systems (Metcalf & Eddy, 2003)

a. Conventional, plug flow systems

The most common activated sludge design used by municipalities and industry operates in the endogenous phase, in order to produce and acceptable effluent in BOD and TTS levels. Conventional aeration represents a “middle of the road” approach because its capital and operating cost are higher than those of the high rate process, but lower than those of the extended aeration plants. Natural flocculation is at the optimum, so the required sedimentation time for the removal of suspended solids from the effluent is minimized.

Settled wastewater and return activate sludge (RAS) enter the front end of the aeration tank and are mixed by diffused air or mechanical aeration. the aeration system is designed to match the oxygen demand along the length of tank by tapering the aeration rates. During the aeration period, adsorption, flocculation, and oxidation of organic matter occur. Activated sludge solids are separated in a secondary settling tank.

b. Extended Aeration, plug flow systems

Extended aeration plants operate in the endogenous phase, but use longer periods of oxidation to reduce effluent BOD levels. This necessitates higher capital and operating cost (i.e., larger basins and more air). In conjunction with lower BOD, extended aeration produces a relatively high-suspended solids effluent when optimum natural settling ranges are exceeded.

Extended aeration design may be necessary to meet effluent BOD requirements when the influent is relatively concentrated in BOD or the waste are difficult to biodegrade. Because extended aeration operates on the declining side of the biomass population curve, net production of excess solids is minimized. Therefore, savings in sludge handling and disposal cost may offset the higher pant capital and operating cost required for extended aeration. The extended aeration process is similar to the conventional plug-flow process except that is operates in the endogenous respiration phase of the growth curve, which requires a low organic loading and long aeration time.

c. Complete Mix Systems

The complete mix activated sludge (CMAS) is an application of the flow regime of a continuous flow stirred-tank reactor. Settled wastewater and RAS are introduced typically at several points in the aeration tank. The organic load, MLSS concentration and oxygen demand are uniform throughout the tank. An advantage of the CMAS is the dilution of shock loads that occurs in the treatment of industrial wastewaters. The CMAS is relatively simple to operate but tends to have low organic substrate concentrations that encourage the growth of filamentous bacteria, causing sludge bulking problems.

d. Contact Stabilization

Due to the highly efficient absorptive capabilities of activated biomass, the time necessary for biomass to capture the colloidal and soluble BOD is approximately 30 minutes to one hour. Oxidation of fresh food requires the normal aeration time of 4-8 hours. In the contact stabilization design, relatively quick sorption time reduces aeration tank volume requirements. The influent waste is mixed with return biomass in the initial aeration tank (or contact tank) for 30-90 minutes. The entire flow goes to sedimentation, where the biomass and its captured organics are separated and returned to a re-aeration tank. In the re-aeration tank the wastes undergo metabolism at a high biomass population. The system is designed to reduce tank volume by containing the large majority of flow for a short period of time.

This process is not generally as efficient in BOD removal as the conventional plant process, due to mixing limitation in the contact basin. Operating costs are equivalent. Due to the un-stabilized state of the biomass at sedimentation, flocculation is inferior. Suspended solids in the effluent are problematic. Because this design exposed only a portion of the active biomass to the raw effluent at a time, it is less susceptible to feed variations and toxicants. For this reason, it can be beneficial for treatment of industrial wastes.

e. Step Feed

In a plug flow basin, the head of the basin receives the waste in its most concentrated form. Therefore, metabolism and oxygen demand are greatest at that point. As the waste proceeds thought the basin, the rate of oxygen uptake (respiration rate) decreases, reflecting the advanced stage of oxidation.

Tapered aeration and step aeration reduce this inherent disadvantage. Tapered aeration provides more oxygen at the head of the basin and slowly reduces oxygen supply to match demand as waste flows through the basin. This results in better control of the oxidation process and reduced air cost.

Step aeration modifies the introduction of influent waste. The basin is divided into several stages, and raw influent is introduced to each stage proportionally. All return microorganisms (sludge) are introduced at the head of the basin. This design reduces aeration time to 3-5 hours, while BOD removal efficiency is maintained. The shorter aeration time reduces capital expenses because a small basin can be used. Operating costs are similar to those of a conventional plant.

f. Oxidation Ditch

Oxidation ditch consists of a ring or oval-shaped channel equipped with mechanical aeration and mixing devices. Screened wastewater enters the channel and is combined with the RAS. The tank configuration and aeration and mixing devices promote unidirectional channel flow, so that the energy used for aeration is sufficient to provide mixing in a system with a relatively long HRT. The aeration/mixing method used creates a velocity from 0.25 – 0.30 m/s in the channel, which is sufficient to keep the activated sludge in suspension. At these channel velocities, the mixed liquor completes a tank circulation in 5 –15 minutes, and the magnitude of the channel flow is such that it can dilute the influent wastewater by a factor of 20-30. As a result, the process kinetics approach that of a CMAS, but with pug flow along the channel.

g. High Purity Oxygen

A staged enclosed reactor is used in the high-purity oxygen. Three or four stages are generally used and the influent wastewater, RAS and high-purity oxygen are added to the first stage. The oxygen partial pressure in the headspace may range from 40 to 60 percent in the first stage to 20 percent in the last stage. At high oxygen partial pressure, higher volumetric oxygen transfer rates are possible so that pure oxygen systems can have a higher MLSS concentration and operate at a shorter HRT and higher VLR than conventional processes. The rate of oxygen addition is 2 to 3 times greater than CAS. Major advantages for pure oxygen systems are the reduced quantities of off-gas if odor control and VOC control are required.

h. Sequential Batch Reactors (SBR)

The SBR is a fill-and-draw type of reactor system involving a single complete-mix reactor in which all steps of the activated sludge process occur. An SBR goes through a number of cycles per day; a typical cycle may consist: fill, aeration, settle and withdrawal of supernatant. An idle step may also be included to provide flexibility at high flows. Mixed liquor remains in the reactor during all cycles, thereby eliminating the need for separate secondary clarifiers. The HRT ranges from 18 to 30 hours, based on influent flow rate and tank volume used.

Table 5 - Activated Sludge Systems

Process	Aeration Retention Time, hrs	MLSS, ppm	DO ppm	Sludge Recycle %	BOD Loading Lb/mft3	F/M Lb BOD / lb MLVSS	Sludge Production	BOD Removal %
High Rate	0.5-3	300 - 1000	0.5-2	5- 15	2.5	1.5 – 5.0	0.65 – 0.85	75-85
Conventional	6 – 8 (diffused) 9-12 (mechanical)	1000 – 3000	0.5-2.0	20-30	20-40	0.2-0.5	0.35-0.55	85-90
Extended Aeration	18-35	3000 - 6000	0.5-2.0	75-100	10-25	0.03-0.15	0.15-0.20	90-95
Step Aeration	3-5	2000 - 3500	0.5-2.0	25-75	40-60	0.2-0.5	0.35-0.55	85-95
Contact Stabilization	3-6	1000 -3000 (aeration) 4000–10000 (contact basin)	0.5-2.0	25-100	60-70	0.2-0.6	0.35-0.55	85-95
Pure Oxygen	1-3	3000-8000	2-6	25-50	100-250	0.25-1.0	0.35-0.55	95-98
Complete Mix	3-5	3000-6000	0.5-2.0	25-100	50-120	0.2-0.6	0.35-0.55	85-95

DEFINITIONS

Activated Sludge - a suspended growth process for removing organic matter from sewage by saturating it with air and microorganisms that can break down the organic matter.

Aeration Tank - a chamber for injecting air and oxygen into water.

Aerobic - a life or a process that occurs in the presence of oxygen.

Algae - aquatic plants which grow in sunlit waters and release oxygen into the water. Most are a food for fish and small aquatic animals, but some cause water quality problems

Anaerobic - a life or a process that occurs in the absence of free oxygen.

Bacteria - small living organisms which help consume the organic constituents of sewage.

Barminutor - a device mounted on bar screens in a wastewater treatment plant to shred material, such as rags and debris, that accumulates on the bars.

Bar Screen - composed of parallel bars that remove larger objects from wastewater.

Biological Nutrient Removal (BNR) - the use of bacteria to remove nutrients from wastewater.

Biomass - microbial growth.

Biosolids - treated sewage sludge solids that have been stabilized to destroy pathogens and meet rigorous standards allowing for safe reuse of this material as a soil amendment.

BOD (Biochemical Oxygen Demand) - a measure of oxygen consumed in biological processes that break down organic matter in water.

Clarifier - known as a settling tank, removes solids from wastewater by gravity settling or by coagulation.

Diffused Air - a technique by which air under pressure is forced into sewage in an aeration tank. The air is pumped into the tank through a perforated pipe and moves as bubbles through the sewage.

Dissolved Oxygen (DO) - the amount of free oxygen in solution in water, or wastewater effluent. Adequate concentrations of dissolved oxygen are necessary for fish and other aquatic organisms to live and to prevent offensive odors.

Effluent - the treated liquid that comes out of a treatment plant after completion of the treatment process.

Eutrophication - the normally slow aging process by which a lake evolves into a bog or marsh and ultimately disappears. During eutrophication, the lake becomes enriched with nutrients, especially nitrogen and phosphorus, which support the excess production of algae and other aquatic plant life. Eutrophication may be accelerated by many human activities.

Floc - a clump of solids formed in sewage by biological or chemical action.

Flocculation - the process by which clumps of solids in sewage are made to increase in size by chemical action.

Grit Chamber - a small detention basin designed to permit the settling of coarse, heavy inorganic solids, such as sand, while allowing the lighter organic solids to pass through the chamber.

Influent - water, wastewater, or other liquid flowing into a reservoir, basin or treatment plant, or any unit thereof.

Lagoon - a shallow pond in which algae, aerobic and anaerobic bacterial purify wastewater. Bacteria on the media decompose additional wastes. Treated water drains from the bed. Solids that accumulate at the surface must be removed from the bed periodically.

Nutrients - elements or compounds essential as raw materials for plant and animal growth and development.

Oxidation – process that involves aerobic bacteria breaking down organic matter and oxygen combining with chemicals in sewage.

Oxidation Pond - an aerated man-made pond used for wastewater treatment.

Pathogens - disease-causing microorganisms, including pathogenic bacteria, viruses, helminths, and protozoans.

Pretreatment - proses that involves treatment of wastes or wastewater by industries performed prior to the discharge to the sewer system.

Primary Treatment - the initial stage of wastewater treatment that removes floating material and material that easily settles out.

Rotating Biological Contactor (RBC) - a wastewater treatment process involving large, closely-spaced plastic discs rotated about a horizontal shaft. The discs alternately move through the wastewater and the air, developing a biological growth on the surface of the discs that removes organic material in the wastewater.

Secondary Treatment - the second stage in most wastewater treatment systems in which bacteria consume the organic matter in wastewater. Federal regulations define secondary treatment as meeting minimum removal standards for BOD, TSS, and pH in the discharged effluents from municipal wastewater treatment facilities.

Sedimentation Tanks - wastewater treatment tanks in which floating wastes are skimmed off and settled solids are removed for disposal.

Sequencing Batch Reactors (SBR) - a variation of the activated sludge process where all treatment processes occur in one tank that is filled with wastewater and drawn down to discharge after treatment is complete.

Settleable Solids - solids that are heavier than water and settle out of water by gravity.

Sewers - a system of pipes that collect and deliver wastewater and/or stormwater to treatment plants or receiving waters.

Suspended Solids - the small particles suspended in water or wastewater.

Trickling Filter - a fixed film process that involves a tank, usually filled with a bed of rocks, stones or synthetic media, to support bacterial growth used to treat wastewater.

Wastewater Treatment Plant - a facility involving a series of tanks, screens, filters, and other treatment processes by which pollutants are removed from water.

NOMENCLATURE

AP	= accounts payable
B	= width of bar (mm),
C	= allowance for side frame.
D	= depth of low (m),
F/M	= Food to micro-organism ratio in the reactor, mg BOD_5 / mg MLVSS .d
Kd	= Kinetic parameter, d^{-1}
Ks	= Saturation constant ,mg BOD_5/L
Px	= Biomass production per day, Kg/d
Q	= Flow, m^3/d
Qe	= Effluent Flow rate, m^3/d
Qr	= Sludge return rate, m^3/d
Qw	= Waste Flow rate, m^3/d
RO2	= Oxygen requirements, kg O_2/d
S_{min}	= Minimum BOD soluble in effluent, mg/L
Se	= BOD soluble in effluent, mg/L
So	= Inflow BOD soluble, mg/L
Sp	= bar spacing (mm),
v	= velocity through the screen (m/s),
V	= Volume of the tank, m^3
W	= screen width (m),
X	= Concentration of Biomass in reactor, mg.MLVSS/L
Xr	= Recycle biomass concentration, mg.VSS/L
Y	= Kinetic parameter, mg.VSS/mg.BOD_5 removed

Yobs = Observed in yield, mg.VSS/mg.BOD_5

Greek Letters

μm = Maximum specific growth rate, d^{-1}
θ = Hydraulic detention time, day
θc = The Solid retention time, day
θm = Minimum Sludge retention time, day

Superscript

MLSS = Mixed liquor suspended solids
MLVSS = Mixed liquor volatile suspended solids
COD = Chemical Oxygen Demand
BOD = Biochemical oxygen demand