BASIC PRINCIPLES
OF
WASTEWATER TREATMENT

PAKISTAN WATER OPERATORS NETWORK

(March-2022)

PREFACE

On behalf of All water utilities in Pakistan PWON is thankful to JICA for providing Support for ***Management of Water & Sanitation Services in Punjab against Covid-19*** through which lectures / webinars were arranged January 2022, to end March 2022, for ***Better Management of Water & Sanitation Services during Outbreak*** as well *as* ***Awareness & Preventive Measures against Covid-19*** *and* ***Preparation of in house Disinfection by Water & Sanitation Utilities*****.**

On demand of PWON members, lectures for capacity building of utilities in Pakistan about various important technical topics were also added along with above lectures / webinars / seminars. All these events were well participated and appreciated by all utilities

On demand of member utilities PWON has published these lectures for capacity building and references for improvement of their day to day working for the benefit of their consumers at large. This book on the topic of **ASIC PRINCIPLES OF WASTEWATER TREATMENT** is published by PWON for the benefit of all its members.

PWON is thankful to Capt. (R) Muhammad Hafeez for Preparing this valuable document.

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CHAIRMAN
PWON, Pakistan

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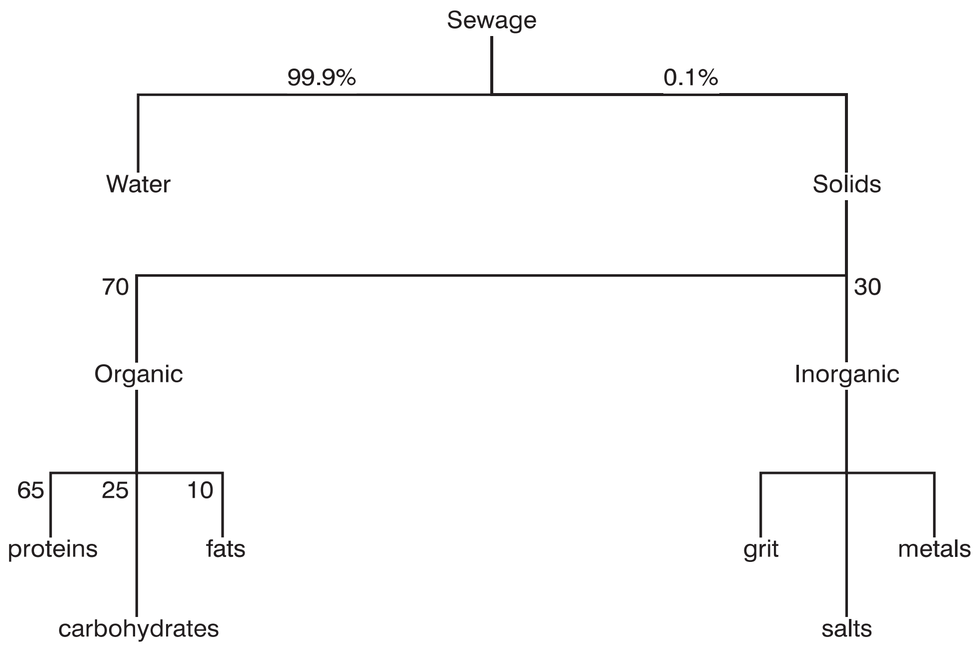
1. WHAT IS WASTEWATER TREATMENT?

- The removal of impurities from wastewater, before it reaches aquifers or natural bodies of water such as rivers, lakes and oceans.
- Since pure water is not found in nature, water is said to be polluted when it contains enough impurities to make it unfit for a particular use, such as drinking, swimming, or fishing.
- Although water quality is affected by natural conditions, the word pollution usually implies human activity as the source of contamination. Water pollution, therefore, is caused primarily by the drainage of contaminated wastewater into surface water or groundwater,
- and wastewater treatment is a major element of water pollution control.

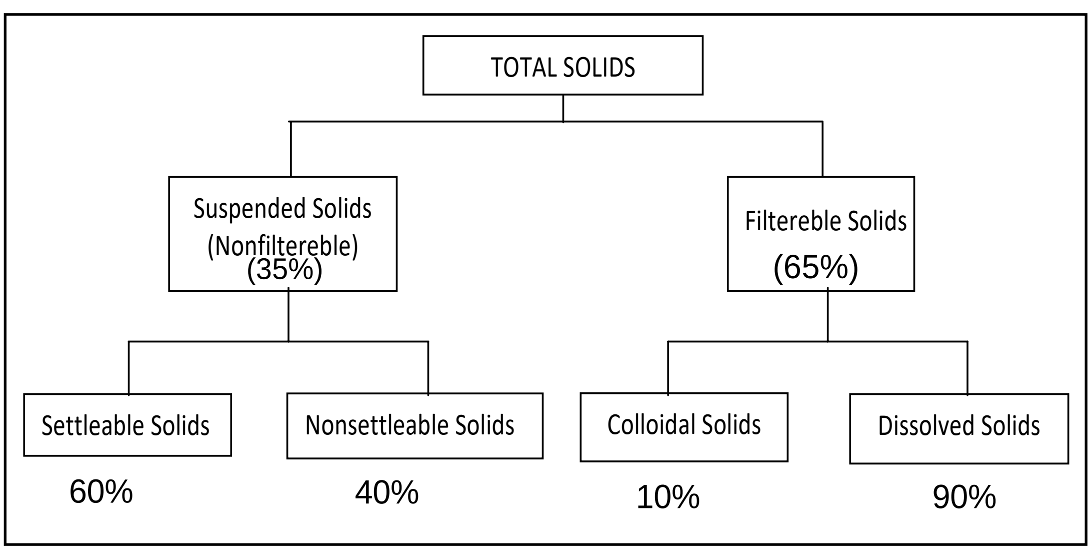
1.1 Main constituents of wastewater

- Wastewater by weight is 99.9% water. It is the 0.1% that we have to remove.
- That 0.1% contains:
- Organic matter: Large source of carbon based compounds from human feces, animals and plants
- Microorganisms (a few of which are pathogenic)
- Inorganic compounds:(Matter, which is not derived from living organisms and contains no organically produced carbon. It includes rocks, minerals and metals).

1.2 Composition of solids in wastewater



1.3 Types of Solids in wastewater



Generally, the operational definition of dissolved solids is that the solids must be small enough to survive filtration through a filter with 2-micrometer.

1.4 Important constituents of concern in wastewater treatment

Pollutant	Reasons of importance
Suspended solids	Development of sludge deposits and anaerobic conditions when untreated wastewater is discharged to aquatic environment
Organic matter	Dissolved oxygen depletion, fish kills
Nutrients	Eutrophication and impairment of water quality
Pathogens	Transmission of diseases
Heavy metals	Toxic to aquatic life. Toxic above specified concentration. Cadmium, Chromium are carcinogenic
Refractory organics	Tend to resist conventional methods of wastewater treatment. Typical examples are phenols and agricultural pesticides

1.5. Microorganisms: key players of the Biological Wastewater Treatment.

- Microorganisms are the key player of the biological wastewater treatment.
- Some say they are the engines of wastewater treatment plant.

All living creatures need:

- Energy
- Carbon
- And Nutrients (nitrogen, phosphorus, sulphur, potassium, calcium, magnesium, etc.) for functions of growth, locomotion, reproduction and others)

Microorganisms also need these to survive.This need of microbial is exploited by wastewater engineers.

Microbial is provided their favorite environment in a controlled manner and ultimately wastewater is treated.

1.6. The main organisms involved in sewage treatment

The main organisms involved in sewage treatment are:

- Bacteria,
- Protozoa,
- Algae
- Fungi,
- Worms.

1.7 Which group of microorganisms will play a role in treatment depends upon the type of process

- The role played by microorganisms in sewage treatment depends on the process being used.
- The microbial mass involved in the aerobic processes consists mainly of bacteria and protozoa.
- Carbonaceous oxidation will be done by heterotrophic bacteria and nitrogenous oxidation by nitrifying bacteria
- In facultative ponds, algae have a fundamental function related to the production of oxygen by photosynthesis.
- In anaerobic treatment systems, the conditions are favorable or even exclusive for the development of microorganisms functionally adapted to the absence of oxygen.

2. MAIN MATERIAL POLLUTANTS IN A NUTSHELL CARBON, NITROGEN, PHOSPHOROUS

2.1 ORGANIC Matter IS A SOURCE OF CARBON

he organic material is composed principally of:

- Proteins (≈ 65%)
- Carbohydrates and (≈ 25 to ≈ 50%)
- Fats (≈ 10%)
- Energy source is chemical reaction.

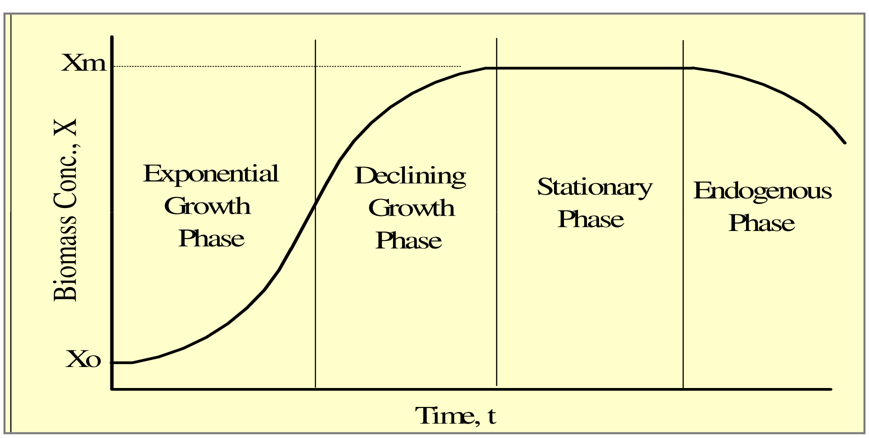
$C + O_2 \rightarrow CO_2 \uparrow +$ ☺☺☺ $+H_2O$☺: Heterotrophic Bacteria

2.2 Fundamental tasks of wastewater engineers.

- Wastewater Engineers deploy bacteria for oxidation of organic matter to get maximum efficiency and output from them.
- The oxidation of organic compounds to carbon dioxide in the presence of free oxygen is the fuel that powers the bacteria.
- So oxygen is essential for an aerobic biological treatment process.
- Understanding how to mix aerobic microorganisms, soluble organic compounds and dissolved oxygen for high-rate oxidation of organic carbon is one of the fundamental tasks of wastewater engineers.

$C + O_2 \rightarrow CO_2 \uparrow +$ ☺☺☺ $+H_2$☺: Heterotrophic Bacteria

2.3 The bacterial growth curve



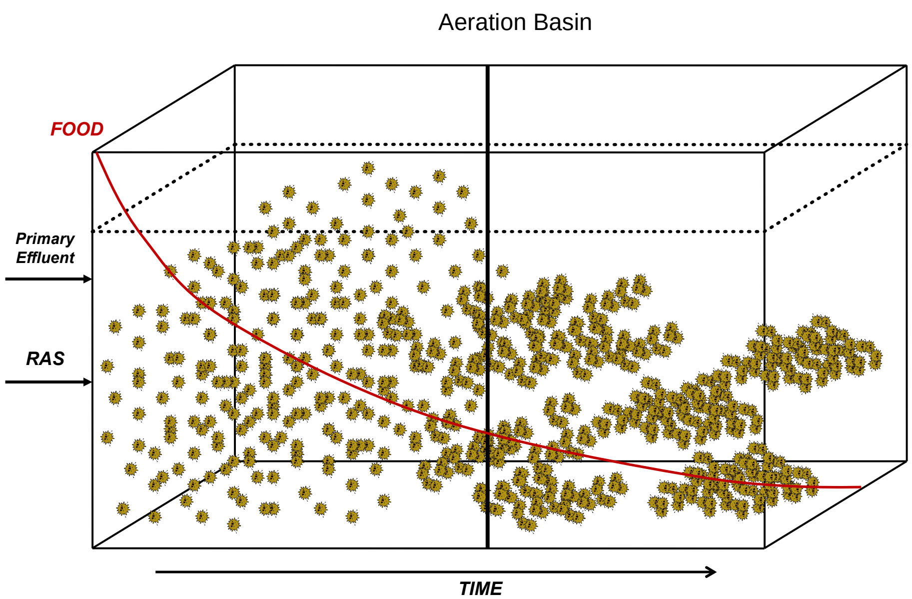
Lag-phase: During this phase bacteria become acclimated to their new surroundings. They are digesting food, developing enzymes and other things required for growth.

Accelerated Growth-phase: The bacteria are growing as fast as they can, since there is an excess of food. The cells are mostly dispersed, not sticking together.

Declining Growth-phase: Reproduction slows down because a lot of food has been eaten and there are now a large number of bacteria to compete for remaining food, so the bacteria do not have enough remaining food to keep the growth rate at a maximum.

Stationary-phase. Not much food is left, so the bacteria cannot increase in number. There is some reproduction, but some cells are also dying, so the number of bacteria remain relatively constant.

Death-phase. The death rate increases with very little if any growth occurring. Therefore, the total number of living bacteria keeps reducing. The bacteria are just trying to keep alive.



- they begin to form a thick outer slime layer.
- As they bump into each other they stick together.
- At first they form small clumps which eventually become large enough to settle.

2.4 Bacteria oxygen demand

- Bacteria use oxygen for oxidation of organic matter. Their oxygen demand is expressed in two ways:
- Biochemical oxygen demand (BOD)
- Chemical oxygen demand (COD)
- 2.4.1 Biochemical oxygen demand (BOD)
- BOD is a measure of the dissolved oxygen used by the microorganisms in the biochemical oxidation of the organic matter. It is measured in mg/L.
- It is the five day measure of BOD5. For typical domestic sewage, the oxygen consumption on the fifth day can be correlated with the final total consumption.
- The BOD represents the quantity of oxygen required to oxidize, the carbonaceous organic matter. It is an indirect indication, therefore, of the biodegradable organic carbon.
- Assume dissolved oxygen at start of process=7mg/l and at day 5=3mg/l.
- BOD5 will be=7-3=4 mg/l
- The rate at which organic matter is oxidized by bacteria is a fundamental parameter in the rational design of biological treatment processes.

2.4.2 Chemical oxygen demand (COD)

- The COD test measures the consumption of oxygen occurring as a result of the chemical oxidation of the organic matter. The value obtained is, therefore, an indirect indication of the level of organic matter present.
- The BOD relates itself with the biochemical oxidation of the organic matter, undertaken entirely by microorganisms.
- The COD corresponds to the chemical oxidation of the organic matter, obtained through a strong oxidant (potassium dichromate) in an acid medium.
- The main advantages of the COD test are:
- the test takes only two to three hours;
- the test results give an indication of the oxygen required for the stabilization of the organic matter.

2.4.3 The ratio of COD/BOD indicates biodegradability of organic matter

- For raw domestic sewage, the ratio COD/BOD5 varies between 1.7 and 2.4.
- Low COD/BOD5 ratio (less than 2.5) (i.e. COD 280 & BOD 120) :
- The biodegradable fraction is high
- Good indication for biological treatment
- Intermediate COD/BOD5 ratio (between 2.5 and 4.0) (i.e. COD 520 & BOD 150):
- The inert (non-biodegradable) fraction is not high
- Treatability studies to verify feasibility of biological treatment
- High COD/BOD5 ratio (greater than 3.5 or 4.0): (i.e. COD 1200 & BOD 300):
- The inert (non-biodegradable) fraction is high
- Possible indication for physical–chemical treatment
- High values show industrial effluent in the wastewater

2.4.4 Ultimate Biochemical Oxygen Demand (BOD_u)

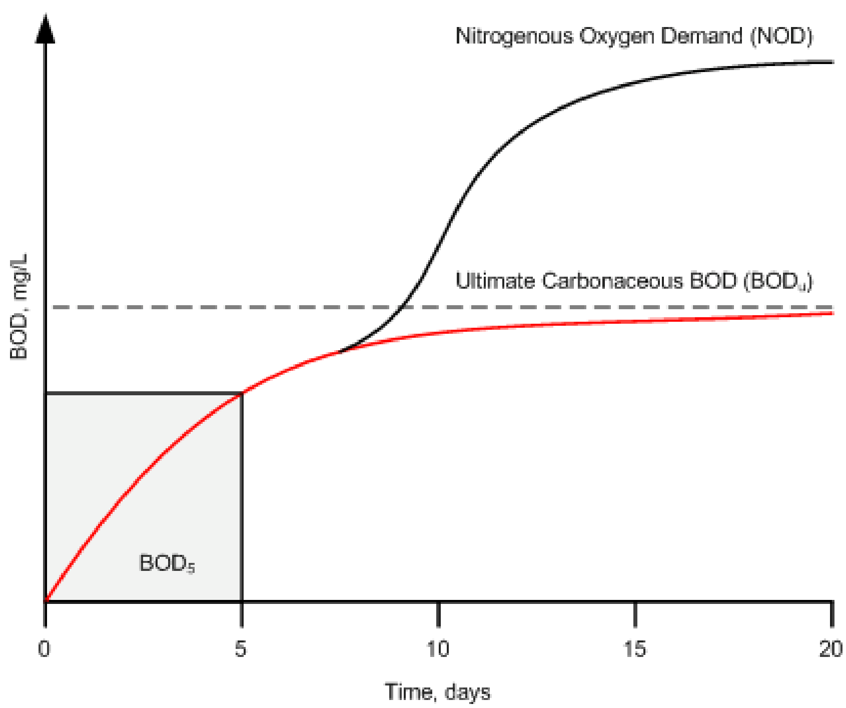
- The BOD5 corresponds to the oxygen consumption exerted during the first 5 days.
- However, at the end of the fifth day the stabilization of the organic material is still not complete, continuing, though at slower rates, for another period of weeks or days.
- For domestic sewage, it is considered, in practical terms, that after 20 days of the test the stabilization is practically complete. Therefore the BODu can be determined at 20 days.
- Various authors adopt the ratio BODu/BOD5 equal to 1.46.

2.4.5 Slow growth rate of the nitrifying bacteria

- About 60 % to 70 % of the organic matter is oxidized after five days.
- If the wastewater contains proteins and other nitrogenous matter, the nitrifying bacteria will also exert a measurable demand after six to seven days.

- The delay in exhibition of the nitrogenous oxygen demand (NOD) is due to the slow growth rate of the nitrifying bacteria, as compared with the growth rate of the heterotrophic bacteria responsible for exertion of the carbonaceous oxygen demand typically known as carbonaceous BOD or simply BOD.
- The nitrification process requires the mediation of two distinct groups: bacteria that convert ammonia to nitrites and bacteria that convert nitrites (toxic to plants) to nitrates

2.4.6 Oxygen Demand with Time



Source: Maier, Raina M., Ian L. Pepper, and Charles P. Gerba. Environmental Microbiology. 2[nd] ed. Burlington, MA: Academic Press, 2009.

Carbon oxidation first for 5 days then nitrogen oxidation 5-8 days

Oxygen demand is almost constant after certain level (2-3mg/l)

2.5 Wastewater strength

- The higher the concentration of organic matter in a wastewater, the 'stronger' it is said to be.
- Wastewater strength is often judged by its BOD5 or COD

- The strength of the wastewater from a community is governed to a very large degree by its water consumption.
- Thus, in the US where water consumption is high (350–400 l/person day) the wastewater is weak (BOD5 = 200–250 mg/l),
- whereas in tropical countries the wastewater is strong (BOD5 = 300–700 mg/l) as the water consumption is typically much lower (40–100 l/person day)

2.5.1 Per capita bod contribution

Per capita load represents the average contribution of each individual (expressed in terms of pollutant mass) per day.

Country	BOD, g/capita.d
US	50-120
Japan	40-45
Denmark	55-68
Germany	55-68
Egypt	27-41
India	27-41

This varies from country to country and the differences are largely due to different water consumption rate.

Total Load=Population*per capita load or Total Load =BOD×Sewage flow rate per capita per day.

Sewage contribution is taken 80-90% of water consumption. So if water consumption is 50 gpcd, the sewage will be 40 gpcd=182 lpcd

BOD contribution will be 41 if BOD is 225 mg/l and sewage contribution is 182lpcd

2.6 Typical characteristics of untreated municipal wastewater

Containments	Low strength	High strength
BOD_5	110	350
COD	250	800
TDS	270	860
TSS	120	400
NITROGEN as (TOTAL N)	20	70
PHOSPHORUS (TOTAL AS P)	4	12
TOTAL COLIFORM NO/100ml	10^6 to 10^8	10^7 to 10^{10}
FECAL COLIFORM NO/100ml	10^3 to 10^5	10^5 to 10^8
CHLORIDES	30	90
SHULPHATES	20	50

2.7. Nitrogen in wastewater

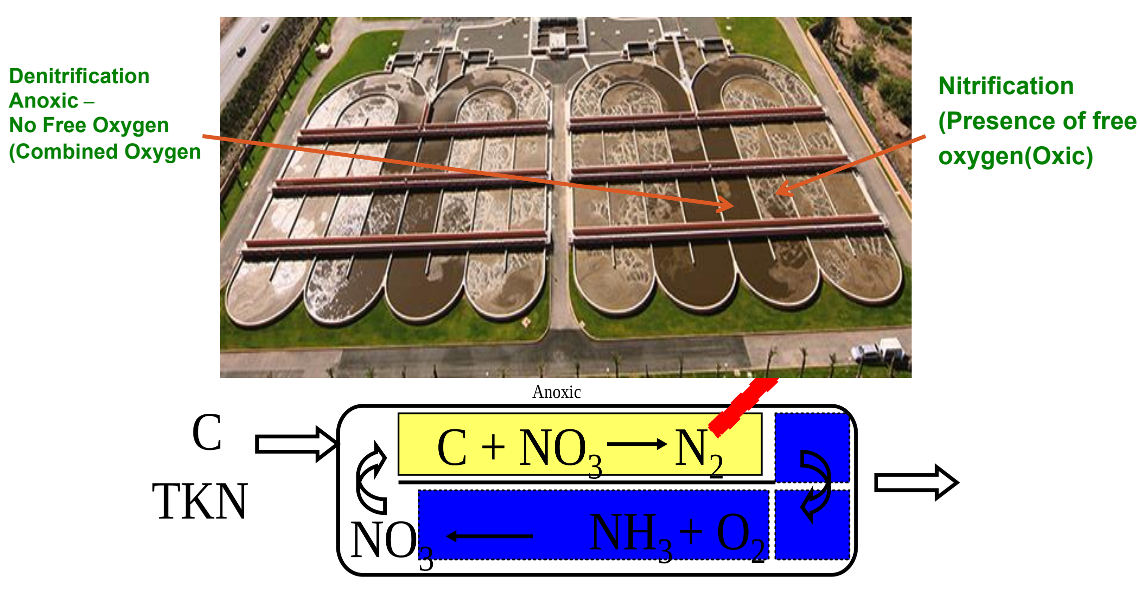
- In raw domestic sewage, the predominant forms are organic nitrogen and ammonia.
- Kjeldahl Nitrogen (TKN) = ammonia + organic nitrogen (prevailing form in domestic sewage)
- TN = TKN + NO_2^- + NO_3^- (total nitrogen)
- Nitrogen is an essential nutrient for algae leading, under certain conditions, to the phenomenon of eutrophication of lakes and reservoirs;
- Nitrogen in the form of free ammonia is directly toxic to fish;
- Eutrophication causes overabundance of algae and plants.
- The excess algae and plant matter eventually decompose, producing large amounts of carbon dioxide.
- This lowers the pH of water. Acidification slows the growth of fish.

2.7.1 Biological nitrogen removal

- Nitrogen is an essential nutrient for the microorganisms responsible for sewage treatment;
- Nitrogen, in the processes of the conversion of ammonia to nitrite and nitrite to nitrate (*nitrification*), which can occur in a WWTP, leads to oxygen and alkalinity consumption;
- Nitrogen in the process of the conversion of nitrate to nitrogen gas (*denitrification*), which can take place in a WWTP, leads to:
- the economy of oxygen and alkalinity (when occurring in a controlled form) or
- the deterioration in the settleability of the sludge (when not controlled).

2.7.2 Nitification & Denitrification In Oxidation Ditch

NITIFICATION & DENITRIFICATION IN Oxidation Ditch



A carbon source (shown in the above equation as CH3 OH) is required for DE nitrification to occur. It may be wastewater with sufficient carbon source.

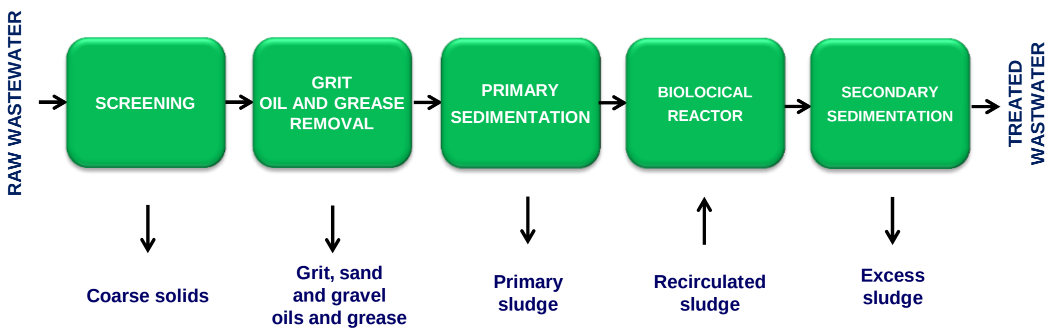
2.8 Phosphorus

- Phosphorus is an essential nutrient for the growth of the microorganisms responsible for the stabilization of organic matter.
- Phosphorus is an essential nutrient for the growth of algae, eventually leading, under certain conditions, to the eutrophication of lakes and reservoirs.
- Phosphorus in detergents can account for up to 50% of the total phosphorus present in domestic sewage.
- Phosphorus in detergents is present, in raw sewage, in the form of soluble polyphosphates or, after hydrolysis, as orthophosphates. *Orthophosphates* are directly available for biological metabolism without requiring conversion to simpler forms.
- This is mostly removed in biological process.
- Biological phosphorus removal (BPR) is accomplished by a group of bacteria collectively known as PAOs (phosphorus-accumulating organisms).
- The PAOs incorporate large amounts of phosphorus into cell biomass, which is subsequently removed from the process by sludge wasting.
- The basic biological phosphorus removal process consists of an anaerobic zone or tank followed by an aeration tank.
- The anaerobic zone is called a selector, since it provides the favorable conditions for growth and proliferation of PAOs, with a short HRT of 0.5 to 1.0 h.

2.9 Pathogens associated with municipal wastewater

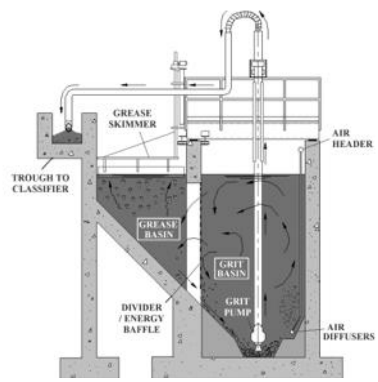
- Coliform bacteria may be treated with disinfection.
- Protozoan cysts and helminthes eggs are mainly removed by physical mechanisms, such as sedimentation and filtration
- Waterborne bacteria
- Protozoa
- Helminthes (Parasitic worm)
- Viruses

2.10 TYPICAL FLOWSHEET OF A WWTP



2.11 Preliminary treatment

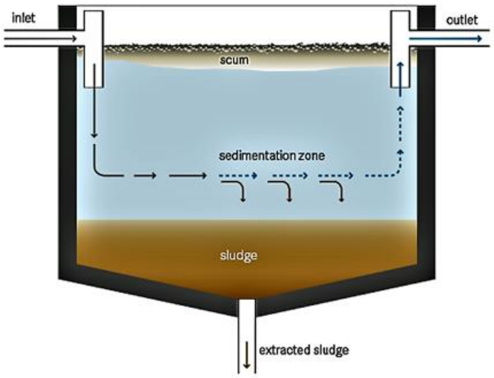
Examples of preliminary treatment are screens for removal of large debris, comminutor for grinding large particles, grit chamber for removal of inert suspended solids, and flotation for removal of oils and grease.

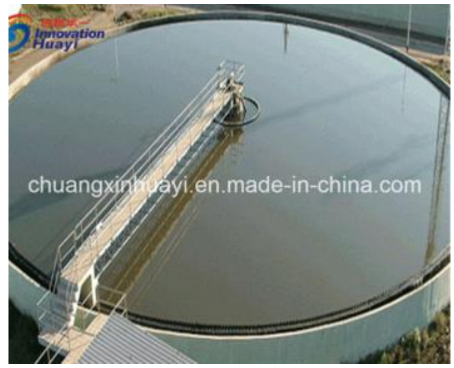


2.12 Primary treatment

Primary Sedimentation

The objective of the primary sedimentation tank is to remove readily settleable solids and floating material and thus reduce the suspended solids content. Primary treatment involves the physical removal of 50-70% of suspended solids and 25-40% of BOD from wastewater,





2.13 Secondary treatment

2.13.1 Suspended growth processes

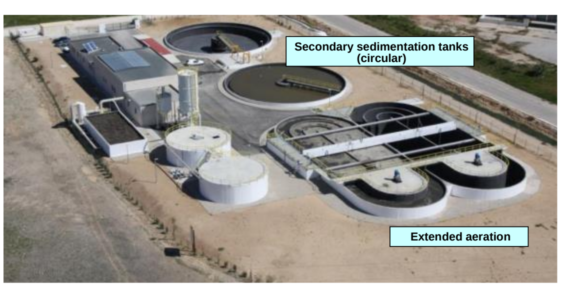
- In a suspended growth process, the microorganisms are kept in suspension in a biological reactor by using a suitable mixing technique.
- The microorganisms use the organic matter as food and convert it to new biological cells, energy, and waste matter.
- Natural purification processes take place over an extended period of time, ranging from days to weeks, depending on the strength of the wastewater and availability of a suitable microbial population.
- The most widely used suspended growth process is the activated sludge process.

2.13.1.1 MAJOR SUSPENDED GROWTH PROCESSES

Activated-sludge process:

- ❖ Conventional (plug-flow);
- ❖ Continuous-flow;
- ❖ Extended aeration.
- ❖ Oxidation ditch

Aerated lagoons.



2.13.2Attached growth processes

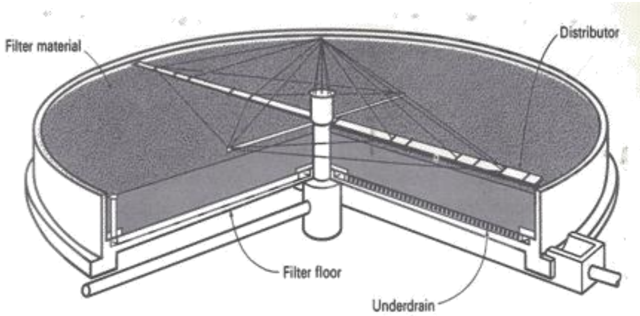
- In attached growth systems the microorganisms are attached to an inert medium, forming a biofilm.
- As the wastewater comes in contact with and flows over the biofilm, the organic matter is removed by the microorganisms and degraded to produce an acceptable effluent.
- Attached growth systems are characterized by a high degree of liquid recirculation (100% to 300%) to the biological reactor.
- The medium is usually an inert material with a high porosity and surface area, e.g. rock, gravel, synthetic media.

Slime layer on media

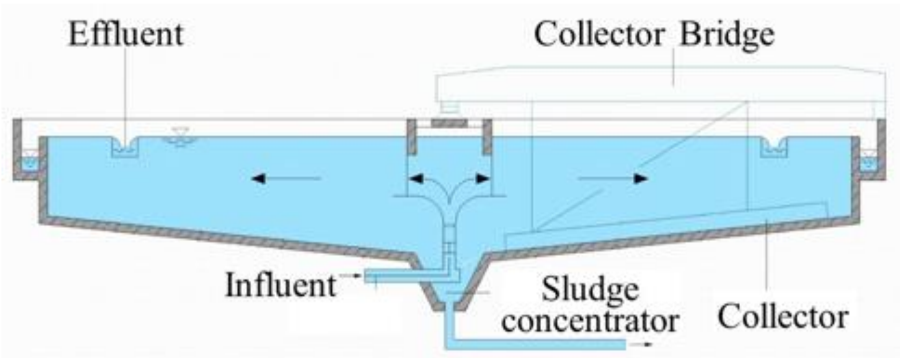
- The outer 0 .1 to 0 .2 mm of biofilm remains Aerobic.
- The inner layers of the biofilm become anaerobic, as oxygen cannot pass into the inner layers due to diffusion limitations.

2.13.3 MAJOR ATTACHED GROWTH PROCESSES

- Trickling filters (low-rate- without recirculation, high rate and super high rate flow-with recirculation);
- Rotating biological contactors;



2.13.4 Secondary Clarification



The term secondary clarification denotes clarification of effluent from secondary biological reactors in settling tanks.

Secondary clarifiers are placed after the biological reactors, and constitute secondary treatment together with the biological unit.

The assumption is that all biochemical reactions take place in the bioreactor, and the function of the clarifier is separation of solids from the liquid fraction and thickening of settled solids in most cases.

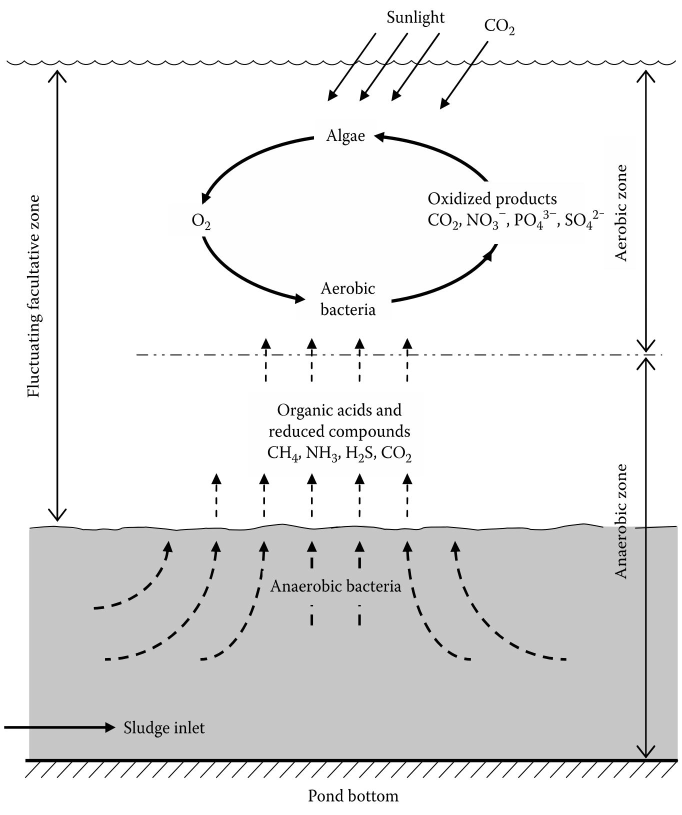
2.14 OND SYSTEM

Anaerobic ponds,

- Which are typically absent of DO and contain no significant algal population. They typically are deeper than other types of ponds

Facultative ponds,

- Which incorporate two different operating modes, aerobic at the surface and , with the settlement of sludge, anaerobic at the base of the pond. These ponds are typically shallower than anaerobic ponds.



Maturation ponds,

- Which essentially are used for polishing of effluent, and are shallower to allow for ultraviolet light penetration and subsequent disinfection.

3.TERTIARY TREATMENT:

Tertiary treatment includes treatment processes used after the secondary, e.g. Following methods are commonly used

Removal	Treatment Method
TSS	Filtration and micro screening
Microorganisms	Sand filtration UV disinfection Maturation Ponds Disinfection with Chlorine or Ozone
Nitrogen	Nitrification/De nitrification
Phosphorus	Chemical presipitation Biological process

4.ANOTHER CLASSIFICATION OF TREATMENT PROCESSES

Aerobic Process:

This works in the presence of free oxygen

Anaerobic Process:

This works in the absence of free oxygen

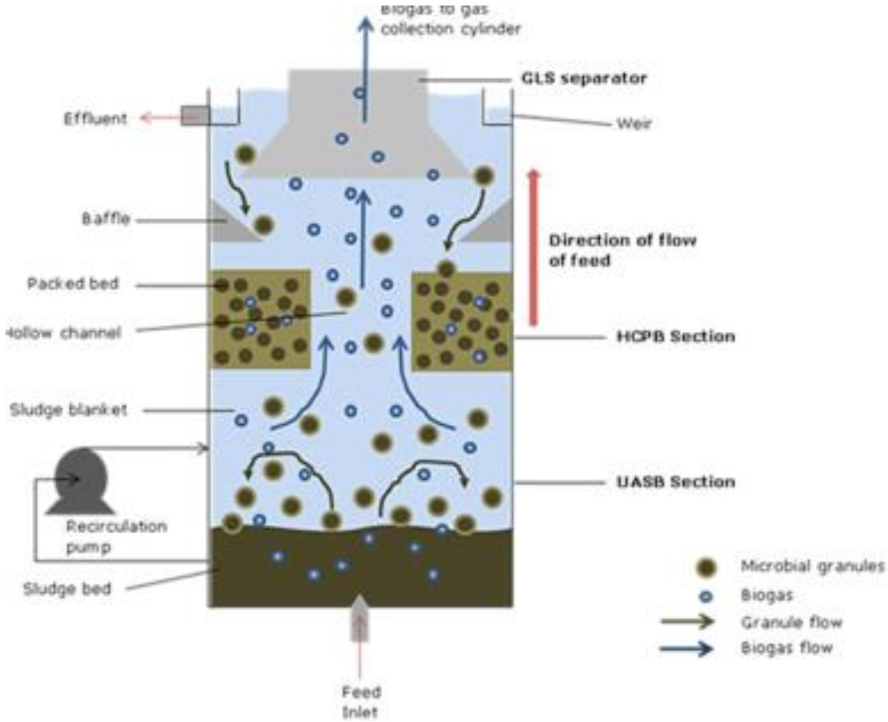
4.1 Aerobic process

- Wastewater flows continuously into the aeration tank or biological reactor.
- Air is introduced to mix the wastewater with the microorganisms, and to provide the oxygen necessary to maintain aerobic conditions.
- The microorganisms degrade the organic matter in wastewater, and convert them to cell mass and waste products.
- Aerobic action (Dissolved (Free) Oxygen Present).
- The chemical equation is;
- $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ (Glucose + oxygen -> carbon dioxide + water+ energy).

4.2 Anaerobic PROCESS

- Anaerobic environment lacks free oxygen but may contain atomic oxygen bound in compounds such as nitrate (NO_3), nitrite (NO_2), and sulfites (SO_3).
- Anaerobic digestion is achieved by obligatory anaerobic bacteria.

- When sulfites are present, the byproduct is hydrogen sulfide.
- When nitrites/nitrates are present, the byproduct is inert nitrogen gas.
- $C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4$
- Energy consideration, lower biomass yield and methane production



Energy consideration, lower biomass yield and methane production

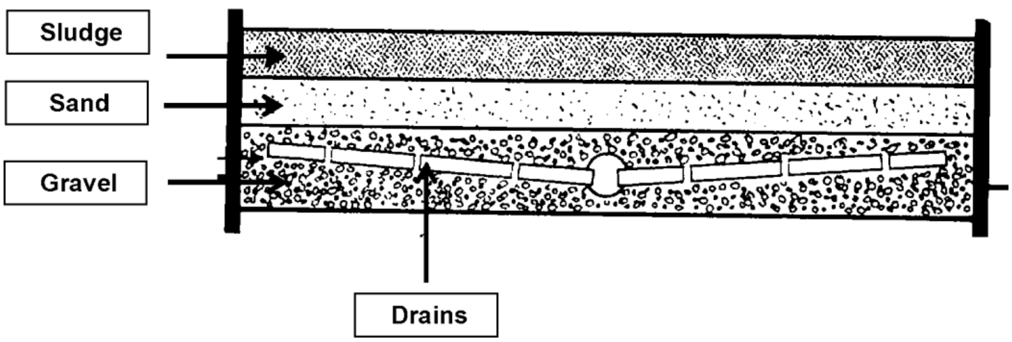
5. SLUDGE: THE SOLIDS BY PRODUCTS

- During the treatment of wastewater sludge is produced. This consists mainly of water (typically >95%).
- Primary sludge Sludge that is separated in the primary settling tank at a wastewater treatment plant and that consists of settleable suspended solids. The water percentage is between the 93 and 97 %. (suspended solids 3-7 %)
- Secondary sludge (also excess sludge/surplus sludge) Biological sludge that is removed from the activated sludge installation (either aerobic or anaerobic sludge, or a mixture of both); the amount of suspended solids is between 0.8 and 1%. • Mixed sludge
- Sludge that exists as the secondary sludge is mixed with the primary sludge.

5.1 Sludge treatment

- Thickening: Gravity or mechanical
- Stabilization: Anaerobic digestion, thermal conditioning
- Sludge dewatering: Drying beds, Sludge lagoons centrifuges, belt filter presses
- Disinfection: Lime addition, composting etc
- Final disposal: Agricultural recycling, Land farming, incineration etc

5.2 Sludge drying beds


Sludge
Sand
Gravel
Drains

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