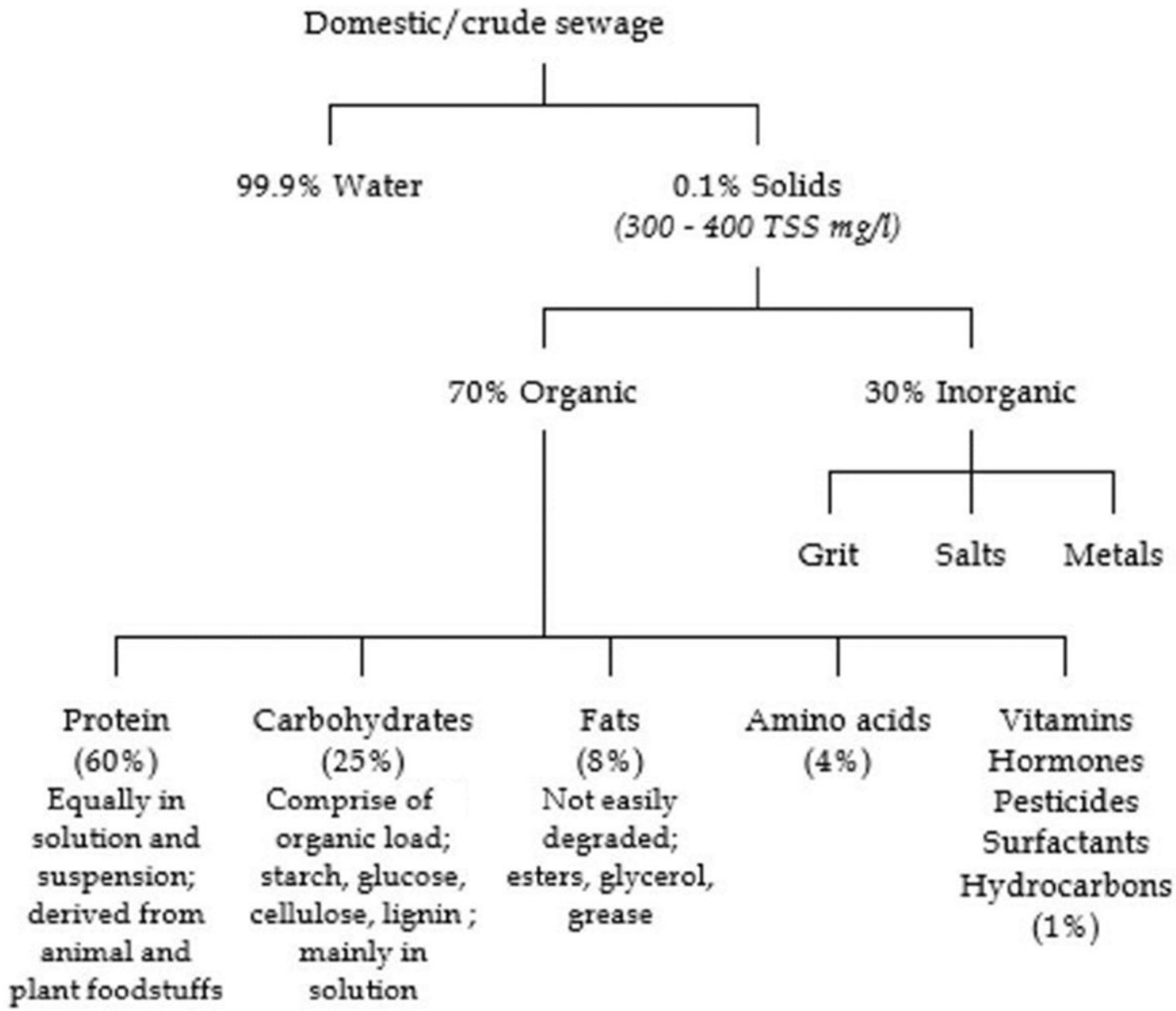
Characteristics of Wastewater

Sewage or Waste water Characteristics

- Wastewater consists of human excreta, waste from domestic processes, trade effluent from industrial processes, infiltration and washing from streets and roofs in raining times. It include every thing else that find its way from consumer's house to sewer.
- Domestic sewage having almost uniform quality, but quantity will be different. Industrial effluents having different quality as well as quantity. Domestic Wastewater characteristics are usually as.
- organic part of sewage carbohydrates (25-50 %) Proteins (40 - 60%) and oil and fats (10%) are present. Inorganic part of sewage salt, grit and metals are present in various composition.

The composition of domestic sewage



Sewage characteristics can be divided into three broad categories:

(1) Physical (Temperature, colour, smell, Solids)

(2) Chemical (BOD, COD, Nutrients and Dissolved solids)

(3) Bacteriological

Physical Characteristics of wastewater

The physical characteristics are its total solids content, odor, temperature, density, color and turbidity.

Fresh sewage is usually gray, light brown, yellowish and having no unpleasant odor.

Foul and unpleasant odor may develop as a result of septic or stale condition.

Its color changes to black or dark brown when sewage becomes stale.

Its odor changes within 2-4 hours due to exhaustion of oxygen and presence of H_2S gas in sewage.

Temperature affect chemical reaction and biological activities.

Solids like total suspended solids (TSS), volatile suspended solids (VSS) and settleable solids affect the operation and sizing of treatment units.

Physical characteristics- Odor

Odor is produced by gas production due to the decomposition of organic matter or by substances added to the wastewater.

Detection of odor: Odor is measured by special instruments such as the Portable H_2S meter which is used for measuring the concentration of hydrogen sulfide.

Compound	Chemical Formula	Odor quality
Amines	CH_3NH_2, $(CH_3)_3H$	Fishy
Ammonia	NH_3	Ammoniacal
Diamines	$NH_2(CH_2)_4NH_2$, $(CH_2)_5NH_2H_{25}$	Rotten eggs
Mercaptans (E. g, methy1 and ethy1)	CH_3SH, $CH_3(CH_2)SH$	Decayed cabbage
Skatole		Fecal matter
Organic sulfides		Rotten cabbage

Physical characteristics- Temperature

Temperature of wastewater is commonly higher than that of water supply. Depending on the geographic location the mean annual temperature varies in the range of 10 to 21°C with an average of 16 °C.

Importance of temperature:-

Affects chemical reactions during the wastewater treatment process.

Affects aquatic life (Fish, ……).

Oxygen solubility is less in worm water than cold water.

Optimum temperature for bacterial activity is in the range of 25°C to 35°C.

Aerobic digestion and nitrification stop when the temperature rises to 50°C.

When the temperature drops to about 15°C, methane producing bacteria become in active.

Nitrifying bacteria stop activity at about 5°C

Density:-

Almost the same density of water when the wastewater doesn't include significant amount of industrial waste.

Color:-

Fresh waste water ⟶ light brownish gray.
With time ⟶ dark gray
More time ⟶ black (septic).

Some times pink due to algae or due to industrial colors.

Turbidity:-

It's a measure of the light – transmitting properties of water.

Chemical Characteristics

In sanitary sewage about 75 % of suspended solids and 40% of filterable solids are organic.

Organic compounds are usually consists of C; H; O; N along with S; P and Iron.

The organic substances found in sewage are Protein (40- 60%);

Carbohydrates (25-50%) and 10% as fats and oils.

small amount of synthetic organic compounds like VOCs, Pesticides, insecticides and Organic Pollutants

Sewage also contain inorganic substances.

Chemical Characteristics

BOD (Biochemical Oxygen Demand): When biodegradable Organic Matters is released into a water body, microorganisms feed on the wastes, breaking them into simpler organic and inorganic substances. When this decomposition occurs in ***aerobic environment*** the process produces non-objectionable, stable end products like CO_2, SO_4, PO_4 and NO_3. A simplified form of Aerobic decomposition is

$$OM + O_2 + \text{Microorganisms} \rightarrow CO_2 + H_2O + C_5H_7NO_2 \text{ (New Cells)} + \text{stable Products like } NO_3; PO_4; NO_3\ldots.$$

When insufficient O_2 is available ***Anaerobic decomposition*** occurs by different microorganisms. They produce end products that can be highly objectionable, including H_2S; NH_3 and CH_4 .

The reaction is $OM + \text{Microorganisms} \rightarrow CO_2 + H_2O + C_5H_7NO_2$ (New Cells) + Unstable Products (NH_3; H_2S; CH_4….). CH_4 is a stable gas, while other products are usually unstable.

Bacteria placed in contact with organic matter will utilize it as food source.

Biochemical Oxygen Demand (BOD)

The amount of oxygen required by the bacteria to oxidize the organic matter present in sewage to stable end products is known as biochemical oxygen demand.

Significance: -

Used in design of waste water treatment plants.

DERIVATION OF BOD EQUATION

Biological oxidation of organic matter by bacteria is considered to be a first order reaction for all practical purposes. In a first order reaction, the rate of reaction is proportional to the concentration of the reactant present. So, we can say that in case of biological oxidation of organic matter by bacteria, the rate of oxidation is proportional to the organic matter REMAINING.

BOD EQUATION

Let L_t = the amount of BOD remaining or the organic matter

remaining at any time t

L_0 = the initial concentration of Organic matter or BOD remaining at

time =0 also known as ultimate BOD

Mathematically dL/dt α -L (the negative sign show that L is decreasing) or dL/dt = -kL where K is reaction rate constant. It depends on a number of factors like nature of waste, ability of microbes to decompose waste and temperature.

Or dL /L = -K′dt

Taking integration, the equation is

$\int_{L0}^{Lt} dL/L = -k \int_{-0}^{t} t$ =ln L_t – ln L_o= -Kt or ln L_t/L_o = -Kt

$L_t/L_o = e^{-Kt}$ or $L_t = L_o e^{-Kt}$

BOD EQUATION

Let 'y' be the concentration of organic matter (BOD) consumed up to time 't'

$y = L_o - L_t$

$y = L_o - L_o e^{-Kt} \Rightarrow y = L_o (1 - e^{-Kt})$

i.e BOD consumed = ultimate BOD $(1 - e^{-Kt})$ in 't' days

Typical value of K = 0.23 per day for domestic sewage at 20°C. Value of 'K' is temperature dependent. $K_T = K_{20} (\theta)^{T-20}$ where $\theta = 1.047$

$K_T = K_{20} (1.047)^{T-20}$

K_T = Value of K at temperature T in ^0C

Limitation in BOD test:

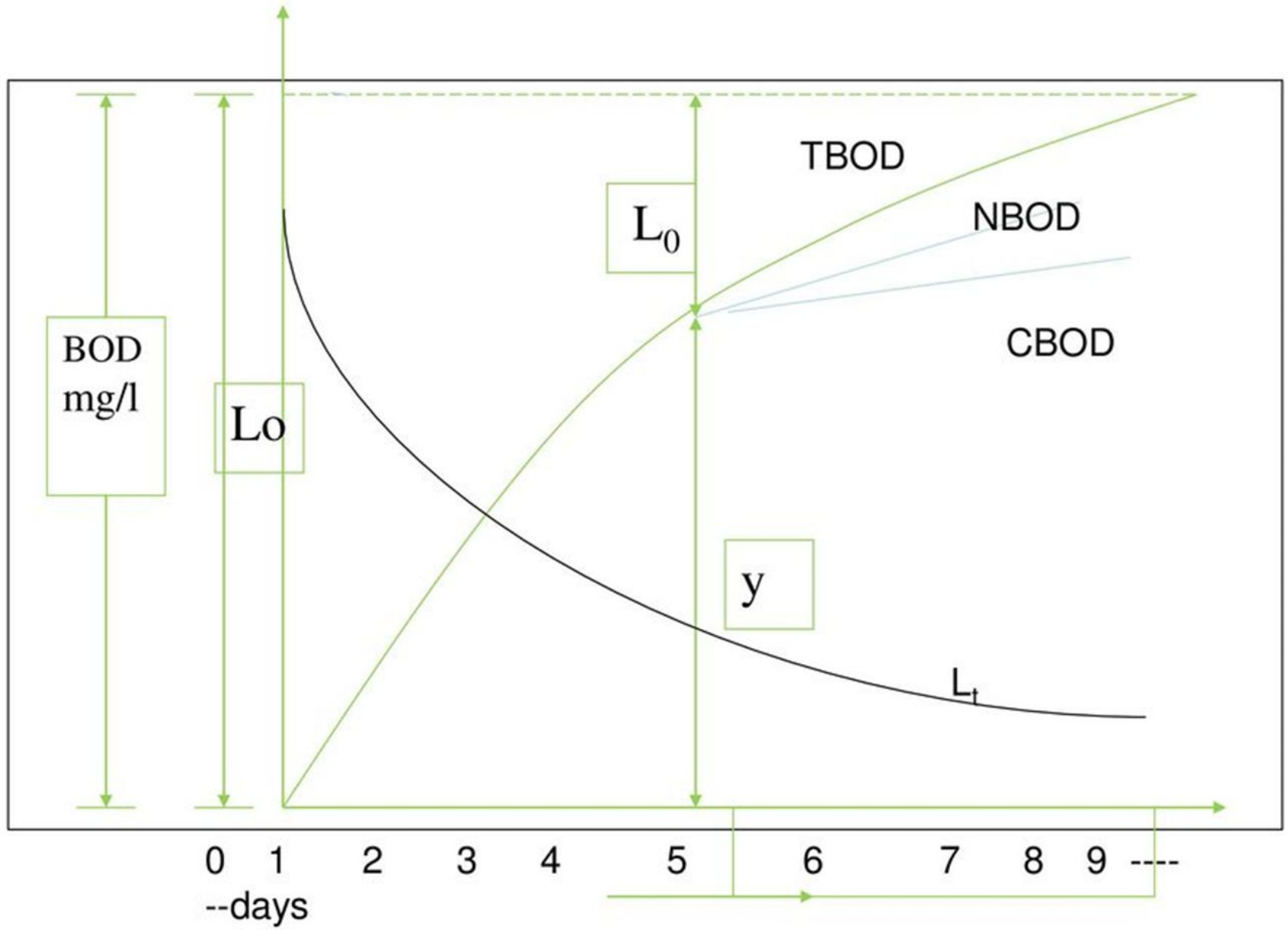
i. A high concentration of active microorganisms required

ii. Pre-treatment is required if toxic materials are present in wastewater

iii. Only biodegradable organics are measured

iv. Long time is required to calculate BOD

BOD Sketch



Example

Determine the 1-day BOD and ultimate BOD for a wastewater whose 5-day 20 °C BOD is 200 mg/L. The reaction constant K= 0.23d^{-1} what would have been the 5-day BOD if it had been conducted at 25°C?

Solution:-

- BOD_t = UBOD – BODr = UBOD $(1-e^{-kt})$ = $L_0(1-e^{-kt})$

$200 = L_0 (1-e^{-0.23x5})$

L_0 = 293 mg/L (this is UBOD)

- Determine the 1-day BOD:-

$BOD_t = L_0 (1-e^{-kt})$

$BOD_1 = 293 (1-e^{-0.23x1}) = 60.1$ mg/L

- Determine the 5-day BOD at 25°C:-

$K_T = K_{20} (1.047)^{T-20} \Rightarrow K_{25} = 0.23 (1.047)^{25-20}$

$BOD_5 = L_0 (1-e -kt) = 293 (1-e^{-0.29x5}) = 224$ mg/L

BOD for Nitrogenous OM

- As Carbonaceous BOD is easily decomposed into various compounds, the Nitrogen which is a critical element for protein synthesis is bound up in complex organic molecules is released as ammonia nitrogen. Similarly the living organisms when died, nitrogen is converted into ammonia. The oxidation of ammonia required oxygen. Also it is an important nutrient for algal growth.
- Increased nitrogen control utilizes aerobic bacteria to convert ammonia(NH_3) to Nitrite (NO_2^-). This type of bacteria is known as Nitrosomonas.

  The Nitrate bacteria (Nitrobactor) convert nitrite to Nitrate ((NO_3^-).

  This process is termed as nitrification.

BOD for Nitrogenous OM

The Nitrogenous Oxygen demand consists of two steps.

$NH_3 + 3\ O_2$ Nitrosomonas $\rightarrow 2\ NO_2^- + 2H^+ + 2H_2O$

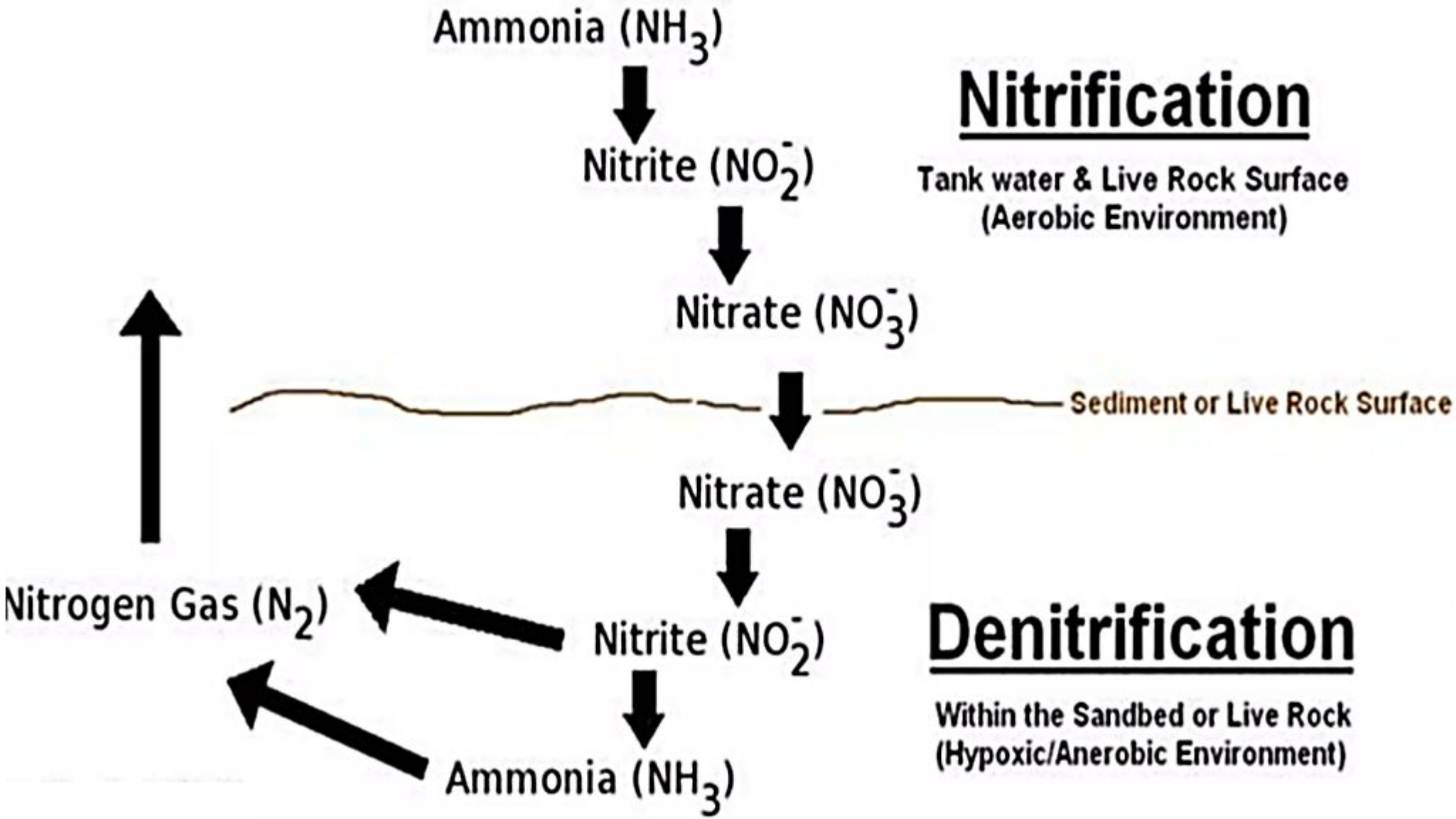
$2\ NO_2^- + O_2 \rightarrow$ Nitrobactor $2\ NO_3^-$

The overall reaction is $NH_3 + 2O_2 \rightarrow NO_3^- + H^+ + H_2O$

As Oxygen is consumed in this reaction. This type of oxygen demand is termed as Nitrogenous Oxygen Demand.

The total concentration of Organic and ammonia nitrogen in sewage is known as Kjeldahl Nitrogen (TKN).

Theoretical NBOD = grams of Oxygen used / Grams of Nitrogen Oxidized =(4*16)/ 14 = 4.57 gram of O_2/ gram of Nitrogen.


Ammonia (NH_3)
Nitrite (NO_2^-)
Nitrate (NO_3^-)
Sediment or Live Rock Surface
Nitrate (NO_3^-)
Nitrogen Gas (N_2)
Nitrite (NO_2^-)
Ammonia (NH_3)
Nitrification
Tank water & Live Rock Surface
(Aerobic Environment)
Denitrification
Within the Sandbed or Live Rock
(Hypoxic/Anerobic Environment)

Chemical Oxygen demand (COD)

Chemical Oxygen Demand (COD): The biodegradable organic matters are degraded completely by microorganisms either of CBOD or NBOD. There are some organic matters like cellulose, phenols, benzene and tannic acid which resists to biodegradation. Similarly other organic matters like pesticides, insecticides and various industrial chemicals are non biodegradable and they are toxic to microorganisms. The COD is a measured quantity that does not depend on microorganisms. To calculate the concentration of oxygen for non biodegradable materials a strong oxidizing agent known as potassium dichromate will be used. The reaction is Organic matter ($C_aH_bO_c$) +$Cr_2O_7^{-2}$+ H2O -→Cr^{+3} + CO_2 + H_2O

COD and TheoD

- The COD test is much quicker than BOD test, but it does not distinguish between the biodegradable and non biodegradable organic matter. The measured COD is usually more than BOD if there is non biodegradable impurity present. If all are the biodegradable organic matter then COD remains the same as that of BOD. Roughly the BOD/COD is 0.4 to 0.8.
- **Theoretical Oxygen Demand (TheoD)**: Organic matter of animal or vegetable origin in wastewater is generally a combination of carbon, hydrogen, oxygen, nitrogen and other elements. If the chemical composition of an organic matter is known then the amount of oxygen required to oxidize it to carbon dioxide and water can be calculated using stoichiometry. This amount of oxygen is known as Theoretical Oxygen Demand. If that oxidation is carried out by bacteria then it is BOD, if by chemical process then it is COD. If a combination of both then it is TheoD

Theoretical Oxygen demand (ThOD): Example

Calculate the Theoretical Oxygen Demand (ThOD) for sugar $C_{12}H_{22}O_{11}$ dissolved in water to a concentration of 100 mg/L. Calculate "TOC".

Solution:-

$$C_{12}H_{22}O_{11} + 12O_2 \rightarrow 12\,CO_2 + 11\,H_2O$$

$$\text{ThOD} = \frac{12 \times 32 g O_2}{342 g_{sugar}} = 1.123 g O_2 / g_{sugar}$$

$$\text{ThOD} = \frac{100 mg_{sugar}}{L} * \frac{1.123 g O_2}{g_{sugar}} * \frac{10^3 mg O_2}{1 g O_2} * \frac{1 g_{sugar}}{10^3 mg_{sugar}}$$

ThOD = 112.3 mg O_2 / L

TOC = 144 g carbon/ 342g sugar = 0.42 gc/ gs

TOC = 0.42 x 100 = 42 mg carbon/L

Chemical Oxygen demand (COD) and Total Organic carbon (TOC)

Example:

Determine BOD_5/COD, BOD_5/TOC, TOC/BOD_5 ratios for the following organic compound ($C_5 H_7 NO_2$). Assume "K" = $0.23d^{-1}$.

1. determine COD:-

$C_5 H_7 NO_2 + 5O_2 \rightarrow 5 CO_2 + NH_3 + 2H_2O$

Mw =113 mw =160

COD = 160/113 = 1.42 mg O_2 / mg $C_5 H_7 NO_2$

2. Determine the BOD_5 of $C_5 H_7 NO_2$:-

$\frac{BOD5}{UBOD} = |-e^{-0.23x5} = 0.68$

BOD5 =0.68 UBOD $\rightarrow$ but COD = UBOD

So BOD5 = 0.68XCOD = 1.42X0.68=0.97 mg BOD/mg $C_5 H_7 NO_2$

3. Determine the TOC of the compound:-

TOC = 5X12/113 = 0.53 mg TOC/mg $C_5 H_7 NO_2$

4. $\frac{BOD5}{COD} = \frac{0.97}{1.42} = 0.68$

$\frac{BOD_5}{TOC} = \frac{0.97}{0.53} = 1.82$

$\frac{TOC}{COD} = \frac{0.53}{1.42} = 0.37$

Note: COD = THOD = UBOD This is true only when the organic compound is assumed to be completely biodegradable

Inorganic Matter

The following are the main inorganic materials of concern in wastewater treatment:

1. **Chlorides:-**

- High concentrations indicate that the water body has been used for waste disposal.
- It affects the biological process in high concentrations.

2. Nitrogen:-

TKN = Total Kjeldahl nitrogen.

= Organic Nitrogen + ammonia Nitrogen (120 mg/l).

3. **Phosphorus:-**

- Municipal waste contains (4-15 mg/l).

4. Sulfur:-

* Sulfate exists in waste and necessary for synthesis of proteins.

Organic matter $+SO_4^{-2} \rightarrow S^{-2} + H_2O + CO_2$

$S^{-2} + 2H^{+} \rightarrow H_2S$

5. Toxic inorganic Compounds:-
Copper, lead, silver, chromium, arsenic, boron.

6. Heavy metals:-
Nickels, Mn, Lead, chromium, cadmium, zinc, copper, iron mercury.

Gases:-

The following are the main gases of concern in wastewater treatment:
N_2, O_2, CO_2, H_2S, NH_3, CH_4

pH:-

The hydrogen-ion concentration is an important parameter in both natural waters and wastewaters. It is a very important factor in the biological and chemical wastewater treatment. Water and wastewater can be classified as neutral, alkaline or acidic according to the following ranges:

PH = 7 neutral.
PH > 7 Alkaline.
PH < 7 Acidic.

Biological/Micro bacteriological Characteristics

Most biological waste and wastewater treatment processes employ bacteria as primary microorganisms; certain other microorganisms may also play an important role.

Bacteria usually consists of 80% water and 20% dry material, of which 90% is organic and 10% inorganics.

An approximate formula for organics fraction is $C_5 H_7 O_2 N$, when phosphorus is considered then the formula is $C_{60} H_{87} O_{23} N_{12} P$.

Main groups of Microorganisms:-

The main microorganisms of concern in wastewater treatment are Bacteria, Fungi, Algae, Protozoa, Viruses, and pathogenic microorganisms groups.

Bacteria:-

Types: Spheroid, rod curved rod, spiral, filamentous. Some important bacteria:-

Pseudomonas:- reduce NO_3 to N_2, So it is very important in biological nitrate removal in treatment works.

Zoogloea:- helps through its slime production in the formation of flocs in the aeration tanks.

Sphaerotilus natuns:Causes sludge bulking in the aeration tanks.

Bdellovibrio: destroy pathogens in biological treatment.

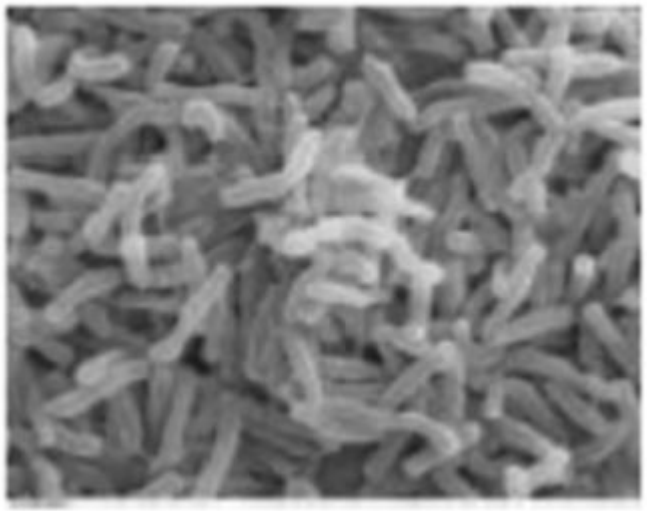
Acinetobacter: Store large amounts of phosphate under aerobic conditions and release it under an – anaerobic condition so, they are useful in phosphate removal.

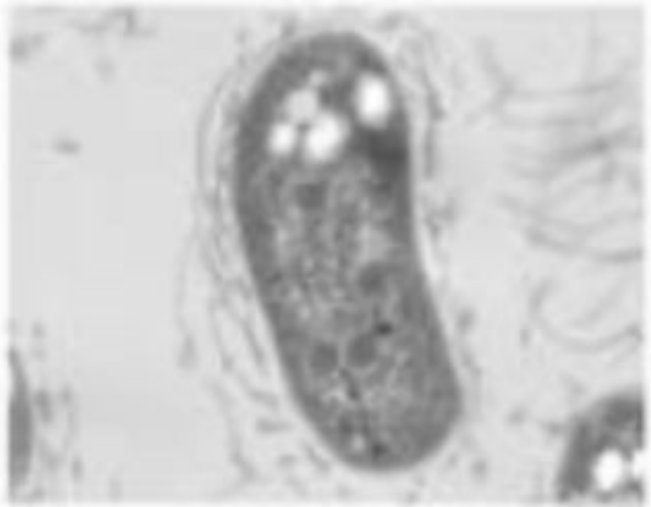
Nitrosomonas: transform NH_4 into NO_2^-

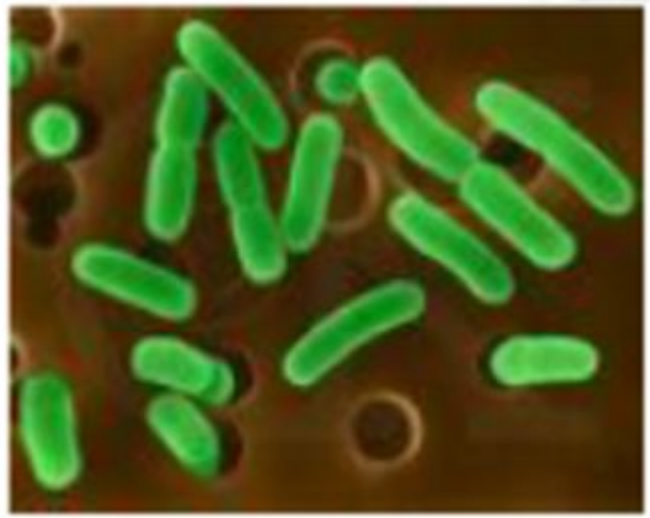
Nitrobacter: transform NO_2^- to NO_3^-

Coliform bacteria:- The most common type is E-Coli or Echerichia Coli, (indicator for the presence of pathogens).

E-Coli is measured in (No/100mL)







Fungi:

- Important in decomposing organic matter to simple forms.

Algae:

- Cause eutrophication phenomena. (negative effect)
- Useful in oxidation ponds. (positive effect)
- Cause taste and problems when decayed. (negative effect)

Protozoa:

- Feed on bacteria so they help in the purification of treated waste water.
- Some of them are pathogenic.



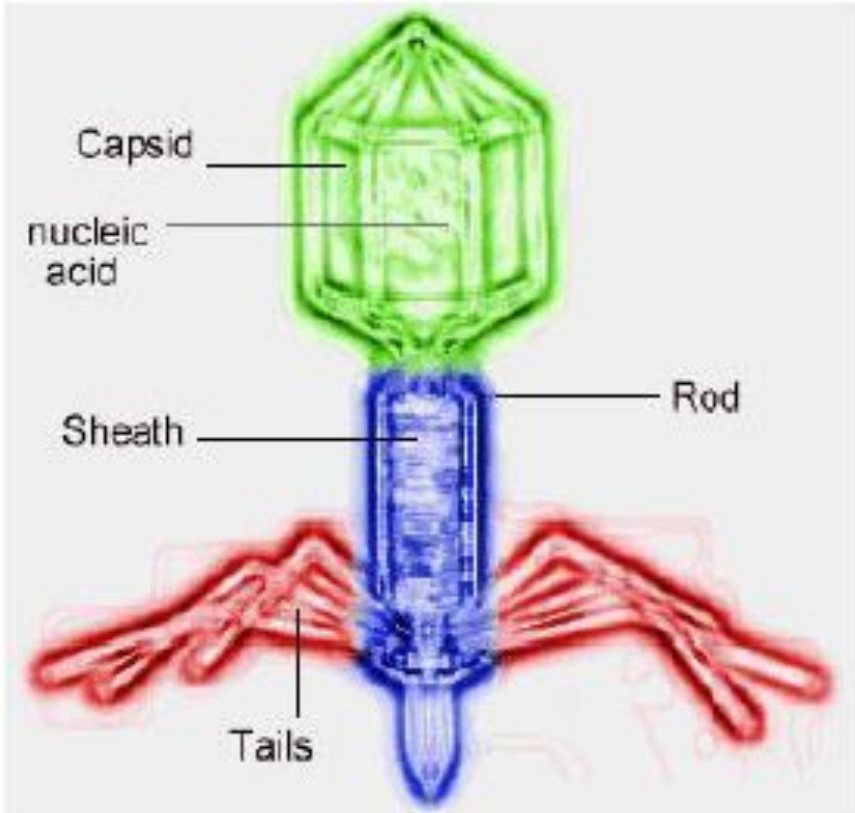


Viruses:

Viruses are a major hazard to public health. Some viruses can live as long as 41days in water and wastewater at 20 °C. They cause lots of dangerous diseases.

Pathogenic organisms:

The main categories of pathogens are:-
Bacteria, Viruses, protozoa, helminthes



Typical Wastewater Composition

Concentration				
Contaminants	**Unit**	**Weak**	**Medium**	**Strong**
Solids, total (TS)	mg/L	350	720	1200
Dissolved, total (TDS)	mg/L	250	500	850
Fixed	mg/L	145	300	525
Volatile	mg/L	105	200	325
Settle able solids (SS)	mg/L	100	220	350
Fixed	mg/L	20	55	75
Volatile	mg/L	80	165	275
Settle able Solids	mg/L	5	10	20
Biochemical oxygen demand, mg/l: (BOD 5-day, 20 °C)	mg/L	110	220	400
Total organic carbon (TOC)	mg/L	80	160	290
Chemical oxygen demand (COD)	mg/L	250	500	1000

Nitrogen (total as N)	mg/L	20	40	85
Organic	mg/L	8	15	35
Free ammonia	mg/L	12	25	50
Nitrites	mg/L	0	0	0
Nitrites	mg/L	0	0	0
Phosphorus (total as P)	mg/L	4	8	15
Organic	mg/L	1	3	5
Inorganic	mg/L	3	5	10
Chlorides[a]	mg/L	30	50	100
Sulfate[a]	mg/L	20	30	50
Alkalinity (as $CaCO_3$)	mg/L	50	100	200
Grease	mg/L	50	100	150
Total coliform[b]	no/100 ml	10^6 - 10^7	$10^7 – 10^8$	$10^7 – 10^9$
Volatile organic compounds (VOC_s)	Mg/L	<100	100 - 400	> 400

Wastewater treatment standards

The most common WWT standards are set for the secondary treatment effluent. The main effluent parameter are: BOD_5, TSS, pH and $CBOD_5$.

*CBOD: (Carbonaceous BOD, from organic compounds and oxidation of inorganic compounds such as ferrous iron)

"secondary treatment" standards in the USA.

Characteristic of discharge	unit	Average 30-day concentration	Average 7-day concentration
BOD_5	mg/L	30	45
TSS	mg/L	30	45
pH	pH units	Within the range 6-9 always	
$CBOD_5^*$	mg/L	25	40

The standards for the removal of nitrogen and phosphorus (N,P) are not included in this table because (N) and (P) need tertiary treatment.

Removal of the coliform bacteria is also regulated according to reuse purpose:-

Fecal coliforms < 500/100 ml (disposed into recreational waters)

1000/100 >ml (for irrigations)