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Environmental Engineering

"Environmental Engineering is a sub-division of Civil Engineering with the thought and practice of environmental sanitation, notably in the provision of safe, palatable, and drinking water supplies; the proper disposal of or recycle of wastewater and solid wastes; the adequate drainage of urban and rural areas for proper sanitation; and the control of water, soil and atmospheric pollution. Furthermore it is concerned with engineering problems in the field of public health, such as control of diseases, the elimination of industrial health hazards, and the provision of adequate sanitation in urban, rural and recreational areas, and the effect of technological advances in the environment"

Question: What is the importance's of environmental engineering? (BUET M.Sc – 2013)

Solution:

Environmental engineers are essential to the protection of the environment as well as the health and safety of humankind. The following represents three ways environmental engineering works to serve humanity and protect the world.

Water Is Life: Water is essential to our existence, for drinking, for eating, for watering crops, for sustaining wildlife and for supporting the ecosystem. Environmental engineers help ensure that water supplies are clean from contaminants, protected from pollution and readily available for people and farms.

Creating Sanitation: In order to help keep people safe from disease, waste must be managed effectively. This requires environmental engineers to determine how to reduce waste, how to properly handle waste at treatment and gray water processing facilities and how to keep waste away from clean water sources.

Reduce Air Pollution: Environmental engineers play a key role in managing pollution and working to reduce the dangerous chemicals and gasses that are produced with industrialization and manufacturing. Limiting greenhouse gasses and reducing further damage from climate change is also an area of focus.

Question: What is environmental impact assessment? Why it is done? (CPGCBL – 2015)

Solution:

Environmental Impact Assessment (EIA) is a process of evaluating the likely environmental impacts of a proposed project or development, taking into account inter-related socio-economic, cultural and human-health impacts, both beneficial and adverse. UNEP defines Environmental Impact Assessment (EIA) as a tool used to identify the environmental, social and economic impacts of a project prior to decision-making. It aims to predict environmental impacts at an early stage in project planning and design, find ways and means to reduce adverse impacts, shape projects to suit the local environment and present the predictions and options to decision-makers. By using EIA both environmental and economic benefits can be achieved, such as reduced cost and time of project implementation and design, avoided treatment/clean-up costs and impacts of laws and regulations. The purpose of Environmental Impact Assessment (EIA) is to identify and evaluate the potential impacts (beneficial and adverse) of development and projects on the environmental system. It is a useful aid for decision making based on understanding of the environment implications including social, cultural and aesthetic concerns which could be integrated with the analysis of the project costs and benefits.

Question: What are the main purpose of EIA? (36th BCS)

Solution:

Essentially, environmental impact assessment (EIA) is an environmental decision support tool, which provides information on the likely impacts of development projects to those who take the decision as to whether the project should be authorised. The purpose of an EIA is to determine the potential environmental, social, and health effects of a proposed development, so that those who take the decisions in developing the project and in authorising the project are informed about the likely consequences of their decisions before they take those decisions and are thereby more accountable.

- *Promote environmentally sound and sustainable development through the identification of appropriate mitigation measures.*
- *Protect the quality and productivity of the natural environment.*
- *Predict and avoid, minimize or offset the adverse significant environmental, social and other relevant effects of development proposals.*
- *Provide information for decision-making on the environmental consequences of any proposed developments.*

Question: *Difference* between EIA and TIA (DMRTP – 2018)

Solution:

EIA	TIA
It denotes environmental impact assessment	It denotes traffic impact assessment
It is a tool for assisting environmental management and to contributing to sustainable development.	It provides guideline for development proponents on how to access the traffic impacts of a proposed development on the state.
Its purpose is to identify potential environmental impacts from proposals as projects or programs.	To fulfill the requirements of BRT system, TIA plays a vital role.

Question: Difference between ETP and STP (HED – 2017)

Solution:

Effluent Treatment Plants or (ETP) are used by companies like pharmaceutical and chemical industry to purify water and remove any toxic and non-toxic materials or chemicals from it. These plants are used by all companies for environment protection. An ETP is a plant where the treatment of industrial effluents and waste waters is done.

Sewage treatment Plants or (STP) is the process of removing contaminants from wastewater and household sewage, both runoff (effluents) and domestic. Its objective is to produce solid waste or sludge suitable for discharge or reuse back into the environment.

Question: Environmental Impact assessment বা EIA এর ধাপগুলো বর্ণনা করুন এবং Environmental Management Plan এর উদ্দেশ্য গুলো বর্ণনা করুন। (LGED – 2019)

Solution:

Environmental Impact Assessment (EIA) is a process of evaluating the environmental impacts of a proposed project or development, taking into account inter-related socio-economic, cultural and human-health impacts both beneficial and adverse.

Steps of EIA: The following points are the main stages of environmental impact assessment.
1. Identification
2. Screening
3. Scoping and Consideration of Alternatives
4. Impact Prediction
5. Mitigation
6. Reporting To Decision-Making Body
7. Public Hearing
8. Review (EIA Report)
9. Decision-Making
10. Post Project Monitoring & Environment Clearance Condition.

Identification: The first step is to define a project and study to understand the range and reach of the project. This helps in deciding the possible zones of environmental impacts.

Screening: Screening is done to see whether a project requires environmental clearance as per the statutory notifications. Screening criteria are based upon: (i) Scales of investment (ii) Types of development (iii) Location of development

Scoping and Consideration of Alternatives: *Scoping is the procedure of identifying the key* environmental issues and is possibly the most important step in an EIA. Scoping means the scope or range of the EIA report. It undertakes the project's effect on the air, water, soil, noise level, air quality and physical impact.

Impact Prediction: Impact Prediction is a way of 'mapping' the environmental consequences of the signifi-cant aspects of the project and its alternatives.

Mitigation: This stage includes recommended actions that can offset the adverse impacts of the project. This is done with the idea of lessening the negative effects and improving the scope for project benefits.

Reporting To Decision-Making Body: The project authorities have to furnish the following documents for environmental appraisal of a development project.

Public Hearing: After the completion of EIA report the law requires that the public must be informed and consulted on a proposed development after the completion of EIA report.

Review (EIA Report): Once the final report is prepared, it may be reviewed based on the comments and inputs of stakeholders.

Decision-Making: The final decision is based on the EIA to approve or reject the project. This is open to administrative or judicial review based on procedural aspects.

Post Project Monitoring & Environment Clearance Condition: Once a project is approved, then it should function as per the conditions stipulated based on environmental clearance. These conditions have to be strictly monitored and implemented.

Environmental Management Plan (EMP): The Environmental Management Plan (EMP) covers the design, construction, operation and maintenance phases of each project component. The EMP identifies the key environmental issues across the project and provides strategies and plans for managing them effectively. It also defines the legal requirements for the project and identifies the regulatory permits and license required for construction activities.

Purpose of EMP:

1. To identify environmental risk & existing management controls
2. To appropriately manage environmental risk
3. Complying with environmental legal requirements
4. To support during implementation.
5. For more effective use of resources
6. To identify site opportunities, constraints and potential sensitive receptors to the works

SANITATION

Sanitation: Sanitation is the hygienic means of promoting health through prevention of human contact with the hazards of wastes.

Classification

1. Human Wastes or Human Excreta
2. Municipal Sewage/ Wastewater
3. Domestic Sewage

Question: Briefly describe the Sanitation Systems. (30th BCS)

Solution:

Based on the fact, whether the waste is stored, treated and disposed of at the point of generation or transported to somewhere else for treatment and / or disposal, sanitation systems may be divided into the following two categories;

1. On-site systems
2. Off-site systems

Based on the methods of collection and conveyance, sanitation systems are of the following types

1. Dry systems
2. Wet systems

On site Systems

1. Wastes are collected, treated and disposed of at the point of generation.
2. Examples are – pit latrines and septic tank systems.

Off-site Systems

1. Waste is collected and transported to somewhere else for treatment and disposal
2. The basic elements of this system are collection, transportation, treatment and disposal and/or reuse.

Low-cost sanitation technologies

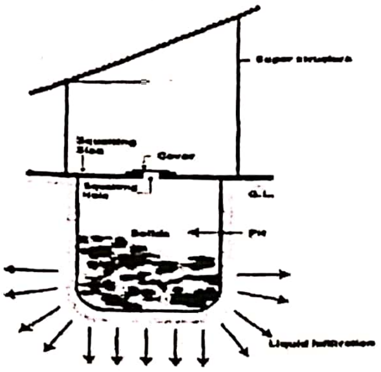
- Pit Latrine
- Pour-flush Latrines

Pit Latrine

The major types of pit latrines include:

- Simple pit latrines
- Ventilated Improved Pit (VIP) Latrines
- Reed Odorless Earth Closet (ROEC)

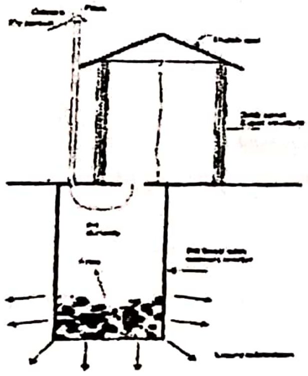
Simple Pit Latrine: Most common and simplest form of excreta disposal in developing countries Consists of a manually dug or bored hole into the ground, an appropriate seat or squatting slab and a shielding superstructure.



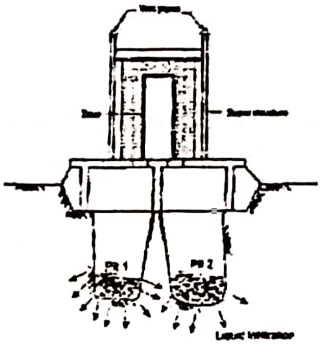
VIP Pit Latrine: Families that use solid materials like newspaper, stone, etc. for anal cleansing are not recommended to use poor-flush latrines as water seal is likely to become blocked or broken. In such cases a latrine direct access to the pit is more appropriate and therefore, ventilated improved pit (VIP) may be a good solution. The basic difference of VIP Latrine from pit latrine is, it requires a vent pipe and design should be such that it maintains continuous airflow. This also increases the cost of super structure.

Types of ventilated pit Latrines:

- Single Pit VIP Latrine
- Twin Pit VIP Latrine



Single Pit VIP Latrine



Twin Pit VIP Latrine

Pit latrin design: The storage volume required to accommodate the sludge that accumulates in the pit during its operational life can be calculated from,
Effective pit volume, $V = C \times P \times N$

V = Effective volume of the pit in m^3
C = Solids accumulation rate in m^3/person/year
P = Number of persons who will be using the latrin
N = Design life in years.

The total pit size for a pit latrin not sxceeding 4 m in depth can be determined as,

$V = 1.33 \times C \times P \times N$

The factor of 1.33 is incorporated to ensure a clear space above the remians of the excreta at the end of the design period. The factor will allow 75% of the pit to be full at the end of this period.

Wet pit		Dry pit	
Anal cleansing: water	Anal cleansing: solids	Anal cleansing: water	Anal cleansing: solids
0.04	0.06	0.06	0.09

Table: Values of solids accumulation rates (m^3/person/year)

Pour flush Latrine: A pour flush toilet is like a regular cistern flush toilet except that the water is poured in by the user, instead of coming from the cistern above. When the water supply is not continuous, any cistern flush toilet can become a pour flush toilet. A water seal prevents flies, mosquitos and odours reaching the latrine from the pit.

The side wall area required for infiltration (Ai, m^2) depends on the wastewater flow (Q, l/day) and the long-term infiltration rate according to the following relationship:

$$A_i = \frac{Q}{I}$$

The wastewater flow depends on the number of users, frequency of flushing, flush volume, urine volumes and amount of water used for anal cleansing. Generally the flow varies between 5-20 lcd. The pit volume, V_l (m^3) corresponding to the sidewall area can now be calculated. For a circular pit of diameter D,

$$V_l = \frac{\pi D^2}{4} h$$

Where $h =$ the height of the sidewall area $= \frac{A_l}{\pi D}$

$$V_l = \frac{A_l D}{4}$$

$$V_l = \frac{Q D}{4 I}$$

For alternating twin-pits, the effective volume of each pit is calculated either using this equation or $V_s = C \times P \times N$, whichever is greater. For single pit pour-flush latrines, the effective volume is given by:

$V = V_s + V_l$

Soil type	Long-term infiltration rate (l/m^2 day)
Sand	50
Sandy loam	30
Porous silty loam, porous silty clay loam	20
Compact silty loam, clay	10

Design values for Long-term infiltration rates for wastewater into various soils

Question: Design a low cast sample pit latrine for the family of 6 persons. The soil in the area is fairly permeable and stable. The ground water table is 5 m below ground. The area is therefore dry. Determine the size of pit latrine for a period of 5 years. (WARPO - 2017)

Solution:

Assume that the pit would be above the groundwater table and therefore can be considered as a dry pit. Hence the value of C, with water being used for anal cleansing can be taken as 0.06 m^3/person/year.

The required volume of the pit, $V = 1.33\ C\ P\ N$

$= 1.33 \times 0.06 \times 6 \times 5$

$= 2.4\ m^3$

Assume, diameter of circular pit, $D = 1.25$ m

Cross sectional area of the pit, $A = \frac{\pi D^2}{4} = \frac{\pi \times 1.25^2}{4} = 1.23\ m^3$

Depth of the pit, $h_i = \frac{\text{volume of the pit}}{\text{cross} - \text{sectional area of the pit}} = \frac{V}{A} = \frac{2.4}{1.23} = 1.95$ m

In case of square/rectangular pit, $h_i = \frac{V}{A} = \frac{2.4}{1.25 \times 1.25} = 1.54$ m

Question: Design leach pits for a twin offset pit pour - flush latrine for a family of a 7 members for a design period of 2.5 years. The cross-section of the pits has to be square. The average waste water flow rate is 12 liters per person per day. The soil is porous silty loam with long - term infiltration rate of 20 liters/m^2 /day. In sketch, show the designed latrine and pit arrangement.

Solution:

Family Members = 7

Design Period, $N = 2.5$ years

Avg. Wastewater flow rate, $q = 12$ liter/person/day

Long term infiltration rate, $I = 20$ liter/m2/day

Now, Total Waste water flow, $Q = 12 \times 7 = 84$ l/d

Area required for infiltration, $A_i = \frac{Q}{I} = \frac{84}{20} = 4.2\ m^2$

Assuming pit width = 1.2 m

Pit Volume, $V_i = \frac{Q\ D}{4\ I} = \frac{84 \times 1.2}{4 \times 20} = 1.26\ m^3$

Now, Case I: single pit pour - flush system:

The effective volume, $V = V_i + V_s = 1.26 + 0.7 = 1.96\ m^3 \approx 2\ m^3$

Considering pit with = 1.2 m

So effective depth, $h = \frac{V}{A} = \frac{2}{1.2 \times 1.2} = 1.39\text{m} \approx 1.5$ m

Assuming 0.5m clear space

So total depth = 1.5 + 0.5 = 2 m

Case II: alternating twin pit power flash system:

Governing volume of pit = 1.26 m^3

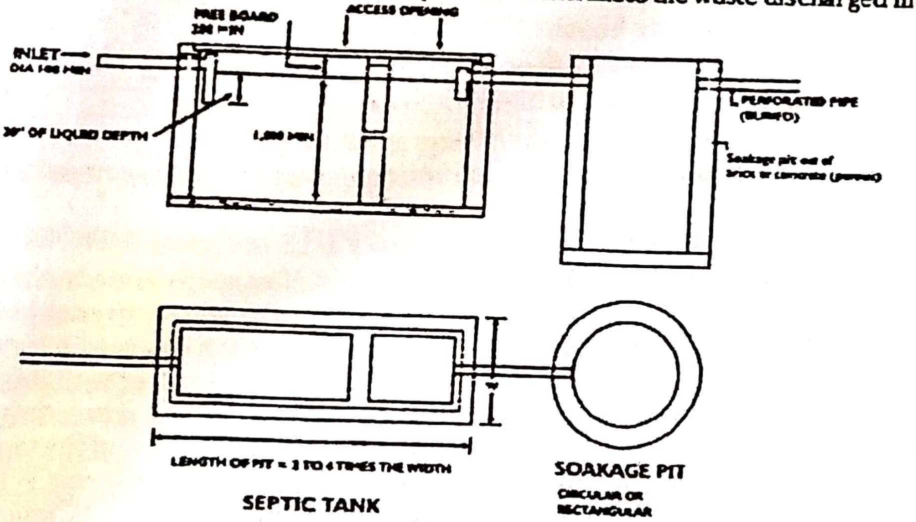
Pit width = 1.2 m

$$\text{Depth of pit} = \frac{V}{A} = \frac{1.26}{1.2 \times 1.2} = 0.875\ m^2$$

Clear depth = 0.5 m

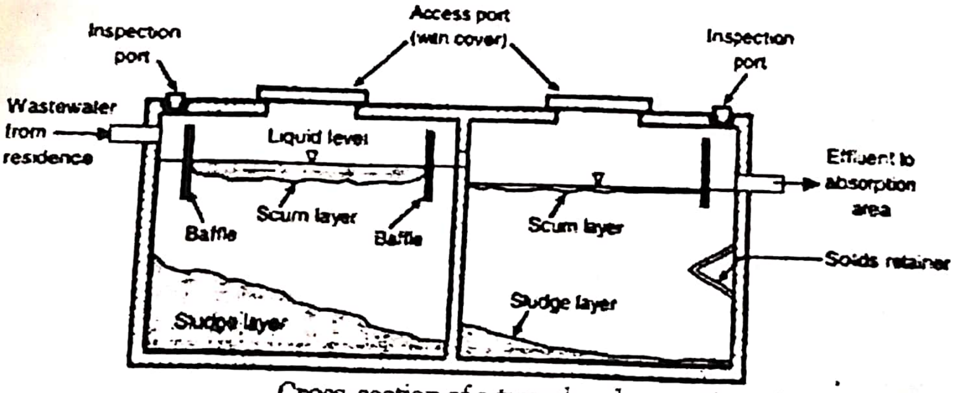
So total depth = 0.875 + 0.5 = 1.375 m ≈ 1.5 m

<u>**Septic tank:**</u> A septic tank is a key component of the septic system, a small-scale sewage treatment system common in areas with no connection to main sewage pipes provided by local governments or private corporations. The term "septic" refers to the anaerobic bacterial environment that develops in the tank and that decomposes or mineralizes the waste discharged into the tank.



Question: একটি 200 user এর Septic tank এর নকশা (Cross-section of Long Section) অঙ্কন করে এর বিভিন্ন অংশের নাম লিখুন। (HED – 2017)

Solution:



Cross-section of a two-chamber septic tank.

Question: Septic tank এবং Soak Well বলতে কী বুঝেন? এগুলি কী কাজে ব্যবহার হয়? (HED – 2017)

Solution:

Septic tank: A tank, typically underground, in which sewage is collected and allowed to decompose through bacterial activity before draining by means of a soak away. A small-scale sewage treatment system common in areas with no connection to main sewage pipes provided by local governments or private corporations. The term "septic" refers to the anaerobic bacterial environment that develops in the tank and that decomposes or mineralizes the waste discharged into the tank.

The essential functions of the septic tank are to:

- receive all wastewater from the house
- separate solids from the wastewater flow
- cause reduction and decomposition of accumulated solids
- provides storage for the separated solids (sludge and scum)
- Pass the clarified wastewater (effluent) out to the drain field for final treatment and disposal.

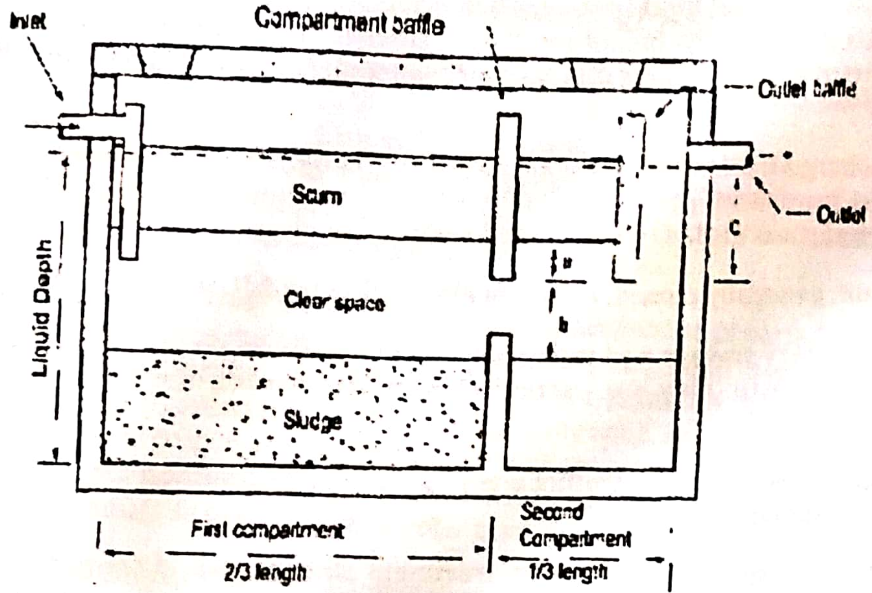
Soak Well: A soakage pit is a circular covered pit (usually 1-1.5 m dia and similar depth) through which the effluent is allowed to be soaked in to the ground. After solids settle in the septic tank, the liquid wastewater (or effluent) is discharged to the soakage pit where they are treated by soil bacteria before finally meeting the ground water reserve. The tank is designed to prevent direct current between the inflow and outflow which is achieved by using pipe tees with submerged end at inlet and outlets. These pipes also prevent escape of floating oil and grease in the effluent. Manhole cover is provided for inspection and withdrawal of sludge. Capacity of the tank should be enough to store wastewaters for one day plus the sludge for 6-months to a year. A fee board of about 0.3m is provided at top. The depth of the tank varies from 1.2m - 1.8 m, and L/B ratio is generally 2-3. Septic tanks and soakage pits are safe methods of treatment and disposal of domestic wastewaters.

Question: Write down the definition of septic tank and function with sketch? (DSCC – 2016)

Solution:

A tank, typically underground, in which sewage is collected and allowed to decompose through bacterial activity before draining by means of a soak away.

Function of septic tank: The essential functions of the septic tank are to: receive all wastewater from the house separate solids from the wastewater flow cause reduction and decomposition of accumulated solids provides storage for the separated solids (sludge and scum) pass the clarified wastewater (effluent) out to the drain field for final treatment and disposal. Septic tank is the first step in the process of sewage conditioning, in a subsurface disposal system. Without it the untreated sewage would quickly clog the receiving soil and prevent the purification process of leaching and soil percolation.



Design Example:

Design a septic tank for the following data:
No. of people = 100
Sewage per capita per day = 120 liters
De-sludging period = 1 year
Length/width = 4: 1

What would be the size of its soak pit if the effluent from the septic tank is to be discharged in it? Assume percolation rate through the soak well to be 125 $l/m^3/d$. assume other data.

Design of Septic Tank

Quantity of sewage per day = 100 x 120 = 12000 liters
Assume, the rate of sludge deposit as = 30 liters/capita/year
Sludge volume = 100 x 30 = 3000 liters
Total tank capacity = 12000 + 3000 = 15000 liters
Assume, Detention time of one day, volume of tank = 15 m^3
Assume depth = 1.5 m
Area of tank = 10 m^2
Use L/B as 4, $4B^2 = 10$, L = 6.3 and B = 1.6 approx.
The dimensions of the tank shall be 6.3 x 1.6 x 1.8 deep including 0.3 m free board.

Design of soak pit

Sewage outflow = 12000 l/day
Percolation rate = 1250 $L/m^3/day$
Volume of soak pit = 12000/1250 = 9.6 m^3
Keep the depth of soak pit as 2 m
Area of pit = 4.8 m^2
Which gives diameter of soak pit as 2.5 m

Important Terms (PGCB – 2015)

Domestic (Sanitary) sewage is the liquid waste which originates in the sanitary conveniences, e.g. Water closets, urinals, baths, sinks etc. of dwellings, commercial or industrial facilities, and institutions. This is sometimes also referred to as black water such as manufacturing and food processing.

Sullage is the liquid discharge from kitchens, wash basins etc. and excludes discharge from WCs and urinals. Sullage, also known as grey water, is less foul than domestic sewage and can be discharged through open surface drains in unsewered areas.

Sewer is a pipe or conduit, generally closed, but normally not flowing full, which carries sewage.

Sanitary sewer carries sanitary sewage and is designed to exclude storm sewage, infiltration, and surface inflow. Industrial waste may be carried in sanitary sewers, depending upon its characteristics.

Storm sewer carries storm sewage and any other waste which may be discharged into the streets or onto the surface of the ground.

Sewerage refers to the entire system of collection, treatment and disposal of sewage through a system of reticulation sewers.

QUALITY OF WATER

Impurities in Water: All the impurities of water can be listed broadly as follows:

Suspended Impurities: Suspended impurities are those which normally remain in suspension. They are macroscopic and make water turbid. The concentration of suspended matter in water is measured by its turbidity. It includes clay, algae, fungi, organic and inorganic matters and mineral matters etc. its size ranges from $0 - 10^{-3}$ mm.

Colloidal Impurities: It is very finely divided dispersion of particles in water. These particles are so small and hence can't be removed by ordinary filters and these are also not visible to naked eye. These are electrically charged and remain in continuous motion. The electric charge is due to presence of absorbed ions on the surface of the solid. Due to this electrical charge, these particles are very small in size, remain in constant motion and do not settle. These impurities are associated with organic matter containing bacteria. Most of the color of water is due to colloidal impurities, whose quantity is determined by color tests. Its size ranges from $10^{-3} - 10^{-6}$ mm.

Dissolved Impurities: Some impurities are dissolved in water when it moves over the rocks, soil, etc. Solid, liquid and gases are dissolved in natural water. These contain organic compounds, inorganic salts and gases etc. The concentration of total dissolved solids is usually expressed in ppm.

Question: Describe briefly quality of water in physical, chemical and biological views. (37th BCS)

Solution:

The quality of water varies daily in every season. So it is necessary to determine the various impurities present in water. The analysis of water is done to determine such impurities and on the basis of these impurities, treatment plants are designed. Examination of water may be divided into three classes:

(1) Physical examination (2) Chemical examination (3) Biological examination

Physical Examination

Temperature: Palatability, viscosity, solubility, odors, and chemical reactions are influenced by temperature. Thereby, the sedimentation and chlorination processes and biological oxygen demand (BOD) are temperature dependent. Most people find water at temperatures of 10 – 15°C most palatable.

Color: The color of water is usually due to presence of organic matter in colloidal condition. Color in water is not harmful but it is objectionable. Pure water is colorless, which is equivalent to 0 color units.

Taste and Odor: Taste and odor in water can be caused by foreign matter such as organic materials, inorganic compounds, or dissolved gasses. The water having bad smell or odour is objectionable & should not be supplied to the public w/s. The unit of odor or taste is expressed in terms of a threshold number.

Turbidity: Turbidity is the cloudiness of water. It is a measure of the ability of light to pass through water. It is caused by suspended material such as clay, silt, organic material, plankton, and other particulate materials in water. Turbidity in drinking water is esthetically unacceptable, which makes the water look unappetizing. Turbidity is measured by an instrument called nephelometric turbidimeter, which expresses turbidity in terms of *NTU.*

Chemical Examination

Total solids: These include the solids in suspension, colloidal and in dissolved form. The quantity of suspended solid is determined by filtering the sample of water through a fine filter, drying and weighing. The quantity of colloidal and dissolved solids is determined by evaporating the filtered water and weighing the residue.

Chlorides: Chloride occurs naturally in groundwater, streams, and lakes, but the presence of relatively high chloride concentration in freshwater (about 250 mg/L or more) may indicate wastewater pollution. Chloride ions Cl^- in drinking water do not cause any harmful effects on public health, but high concentrations can cause an unpleasant salty taste for most people.

Alkalinity: The alkalinity of water is its acid-neutralizing capacity comprised of the total of all titratable bases. The measurement of alkalinity of water is necessary to determine the amount of lime and soda needed for water softening.The high levels of either acidity or alkalinity in water may be an indication of industrial or chemical pollution.

Hardness: Hardness is a term used to express the properties of highly mineralized waters. The dissolved minerals in water cause problems such as scale deposits in hot water pipes and difficulty in producing lather with soap. Calcium (Ca^{2+}) and magnesium (Mg2+) ions cause the greatest portion of hardness in naturally occurring waters.

pH value: pH is one of the most important parameters of water quality. It is defined as the negative logarithm of the hydrogen ion concentration. pH ranges from 0 to 14, with 7 being neutral. pH of less than 7 indicates acidity, whereas a pH of greater than 7 indicates a base solution. Pure water is neutral, with a pH close to 7.0 at 25°C.

Dissolve gases: Dissolved oxygen (DO) is considered to be one of the most important parameters of water quality in streams, rivers, and lakes. It is a key test of water pollution. The higher the concentration of dissolved oxygen, the better the water quality.

Nitrogen & its compounds (nitrate, nitrous): There are four forms of nitrogen in water and wastewater: organic nitrogen, ammonia nitrogen, nitrite nitrogen, and nitrate nitrogen. If water is contaminated with sewage, most of the nitrogen is in the forms of organic and ammonia, which are transformed by microbes to form nitrites and nitrates. A high concentration of nitrate in surface water can stimulate the rapid growth of the algae which degrades the water quality. Excessive nitrate concentration (more than 10 mg/L) in drinking water causes an immediate and severe health threat to infants.

Biochemical oxygen demand: Bacteria and other microorganisms use organic substances for food. As they metabolize organic material, they consume oxygen. The organics are broken down into simpler compounds, such as CO_2 and H_2O, and the microbes use the energy released for growth and reproduction. When this process occurs in water, the oxygen consumed is the DO in the water. If oxygen is not continuously replaced by natural or artificial means in the water, the

DO concentration will reduce as the microbes decompose the organic materials. This need for oxygen is called the biochemical oxygen demand (BOD). The more organic material there is in the water, the higher the BOD used by the microbes will be. BOD is used as a measure of the power of sewage; strong sewage has a high BOD and weak sewage has low BOD.

Biological Examination

Bacteria: Bacteria are single-celled micro-organisms with rigid cell walls. Some bacteria are beneficial to the humans and some types are harmful and cause diseases. These size ranges from 0.15 μ to 5 μ in diameter and 0.3 μ to 60 μ in length.
Following are some common types of bacteria:

- Pathogenic bacteria: These cause diseases
- Non-pathogenic bacteria: These do not cause diseases
- Aerobic bacteria: Bacteria those need oxygen to live are aerobic bacteria.
- Anaerobic bacteria: Can live without oxygen.
- Faculative bacteria: Can live with or without oxygen.

Algae: Algae are considered as simple, photo synthetic plants with unicellular organs of reproduction. In fresh water, algae are generally microscopic in size whereas in salty water these are in the form of cells of several hundred meters in length. Algae impart objectionable taste and odors to water but may create problems in treatment of water by clogging the filter beds.

Protozoa: These are unicellular animals that reproduce by binary fission. It causes amoebic dysentery. These are bacteria eaters and thus destroy the pathogens. These are of various types such as amoeboid, flagellate and ciliate protozoa.

Viruses: Viruses are infectious agents of both plants and animals cells. Due to their ultramicroscopic size, they can only pass through an ultramicroscopic filter. Their sizes range from 10 to 500 milli-microns. It initiates infection by attaching itself by its tail to the wall of bacterial cell.

Question: Define potable and palatable water. Which one can be used for drinking purposes? What are the basic requirements of drinking water? (30th BCS)

Solution:

Potable water is water that has been treated and disinfected so that it is free from disease-producing organisms, poisonous substances, chemical or biological agents, and radioactive contaminants which make it unfit for human consumption or other uses.

Palatable water is water that is pleasing in appearance and taste. It is significantly free from color, turbidity, taste, and odor. It should also be cool and aerated.

Potable water is water that is considered safe to drink.

Basic requirements of drinking water

- The water should be free from contaminants.
- The water should be alkaline.
- It is free of unpleasant odors, tastes and colors, and is within reasonable limits of temperature.
- It contains no toxins, carcinogens, pathogenic micro-organisms, or other health hazards.

Standards for drinking water

Water Quality Parameters	Bangladesh Standards (mg/L)	WHO Guide Line
Arsenic	0.05	0.01
BOD_5 Day, 20^{0}C	0.2	-
Boron	1.0	-
Cadmium	0.005	0.003
Calcium	75	-
Chloride	150 – 600	250
Chlorine (Residual)	0.2	-
COD	4	-
Color	15 Hazen	-
Copper	1	2
DO	6	-
Fluoride	1	1.5
Hardness as $CaCO_3$	200 – 500	500
Iron	0.3 – 1.0	0.3
Odor	Odorless	-
pH	6.5 – 8.5	6.5 – 8.5
Salinity	- %0	-
Sodium	200	-
Total Suspended Solids	10	-
Temperature	20 – 30^{0}C	
Turbidity	10 NTU	5 NTU
Zinc	5	-

Reference - Department of Public Health Engineering, Bangladesh.

Question: Write down the standard value of the following parameters. (TGTDCL – 2018)

Solution:

Parameters	Bangladesh Standard	WHO standard
Arsenic	0.05 mg/L	0.01 mg/L
BOD_5 (20°C)	0.2 mg/L	0.2 mg/L
Iron	0.3 - 1.0 mg/L	0.3 mg/L
Turbidity	10 JTU/NTU	5 JTU/NTU
TDS	1000 mg/L	1000 mg/L

Question: Write down the ECR values for As, Fe, TC, Turbidity and TDS. (DPDC – 2019)

Solution:

Parameters	ECR values
Arsenic	0.05 mg/L
Iron	0.2 mg/L
Total dissolved solids	0.3 - 1.0 mg/L
Turbidity	10 JTU/NTU
TC	1000 mg/L

WATER TREATMENT

Objectives: The main objective of the treatment process is to remove the impurities of raw water and bring the quality of water to the required standards. Following are the main objectives:

- To remove the dissolved gases, turbidity and color of water.
- To remove the unpleasant and objectionable taste and odor's from the water.
- To kill all the pathogenic germs which are harmful to human health.
- To make water fit for domestic use as cooking and washing and other purposes.
- To eliminate the corrosive properties of water which affects the conduits and pipes.

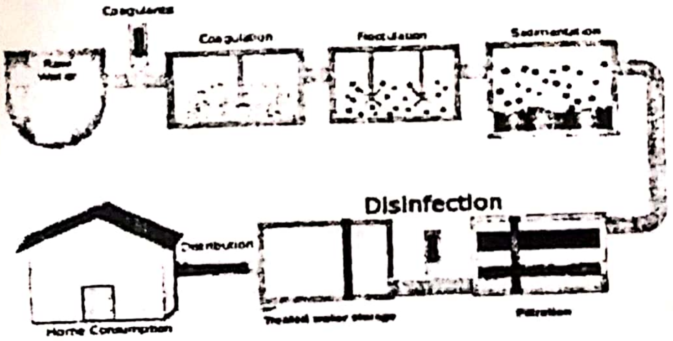
Water Treatment System

Process	Impurities
1. Screening	Floating matters as leaves, dead animals, etc.
2. Plain Sedimentation	Suspended impurities, clay, silt, etc.
3. Sedimentation with Coagulation	Fine suspended matters & Colloidal matters
4. Filtration	Micro-organisms
5. Aeration	Dissolved gases, taste & odour
6. Water Softening	Hardness of water
7. Disinfection	Pathogens

Question: Write down the steps for water treatment process. (TGTDCL – 2018)

Solution:

1. Screening
2. Coagulation
3. Flocculation
4. Sedimentation
5. Filtration
6. Dis-infection
7. Distribution



Screening: Water from surface sources contains floating bodies, suspended matter, debris, etc. are removed by providing screen at the intake point and the process is called screening. Screens may of following to types: (I) Coarse Screen (II) Fine Screen

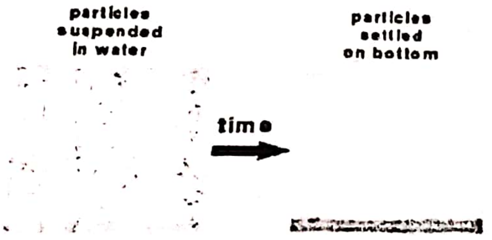
Coarse Screen

- Coarse screen or bar screen is used to remove grosser floating materials.
- These are mostly in the form of grill of bars.
- Bars are generally of 25 mm size and are spaced at 75 to 100 mm c/c spacing.
- Mostly bars are kept inclined at slopes of $(3-6)\ V: 1H$

Fine Screen

Fine screens are used at surface water intakes; sometimes alone and sometimes following a coarse screen. In order that fine screens do not get clogged up, some device is set up to clean it continuously.

Plain sedimentation: Plain sedimentation is the process of removing suspended matters from the water in the tank, so that suspended matter may settle down in the bottom of tank due to gravity. It is designed to reduce the velocity of water, so as to permit suspended solids to settle down by gravity. It is adopted so that less quantity of chemicals is required in the subsequent treatment process.



Purpose of Sedimentation

- To remove coarse dispersed phase.
- To remove coagulated and flocculated impurities.
- To remove precipitated impurities after chemical treatment.
- To settle the sludge (biomass) after activated sludge process

Theory of Settlement

Any particle which does not alter its shape, size and weight while rising or settling in any fluid is called discrete particle. All the particles, having more specific gravity than the liquid; will move vertically downward due to gravitational force. When any discrete is falling through a quiescent fluid, it will accelerate until the frictional resistance or drag force becomes equal to the gravitational force acting upon the particles. At such stage the particle will settle at uniform velocity. The uniform velocity is called 'settling velocity' and is a very important factor.

Newton's Formula

$$v_s = \sqrt{\frac{4}{3}\frac{g}{C_D}\frac{(\rho_s - \rho)}{\rho} d} \text{ or } \sqrt{\frac{4}{3}\frac{g}{C_D}(S_s - 1)\, d}$$

v_s = settling velocity of particle
C_D = drag coefficient
ρ_s = mass density of particle
ρ = mass density of fluid
Determination of C_D

For Re between $0.5 - 10^4$, $C_D = \frac{24}{R_e} + \frac{3}{\sqrt{R_e}} + 0.34$

For Re $> 10^3$ to 10^4, $C_D = 0.4$

For Re < 0.5, $C_D = \frac{24}{R_e}$

Where, Re = Reynolds no.

$$Re = \frac{\rho\, v_s\, d}{\mu} = \frac{v_s\, d}{v}$$

Here, v = kinematic viscosity

Stoke's Formula

The settling velocity of a spherical particle is expressed by stokes law which takes the above three factors into account.

$$v_s = \frac{g}{18}(S_s - 1)\frac{d^2}{v} \quad \text{for d} < 0.1 \text{ mm}$$

$$v = \frac{\mu}{\rho}$$

Where v_s = velocity of settlement of particle in m/s.
G = specific gravity of the particles.
g = acceleration due to gravity
d = diameter of the particles.
v = kinematic viscosity of water in m²/s
μ = viscosity if water in centistokes (1 centistokes = 0.01 cm²/s)

The above stokes equation was valid for d < 0.1mm in which viscous force predominates over inertial force. This is called the streamline settling. Since the viscosity is dependent upon temperature, the above equation can be written as,

$$v_s = 418\,(S_s - 1)\, d^2 \left(\frac{3T + 70}{100}\right) \quad \text{for d} < 0.1 \text{ mm}$$

If however, the settling particles are larger than 1.0 mm, the nature of settling becomes turbulent settling and is governed by Newton's equation given by,

$$v_s = \sqrt{g\, d\, (S_s - 1)} \quad \text{for d} > 1.0 \text{ mm}$$

Grit Particles, however generally lie between 0.1 mm and 1 mm in the transition where settling velocity is given by Hazen as,

$$v_s = 418\,(S_s - 1)\, d \left(\frac{3T + 70}{100}\right) \quad \text{for, } 0.1 \text{ mm} < \text{d} < 1.0 \text{ mm}$$

Design criteria of sedimentation tank

Velocity of flow: 0.15 – 0.30 cm/min
Detention period: 4 – 8 hours
Shape: Generally rectangular or circular
Size: For circular, dia = 60 cm
For rectangular, B = 12 m; Depth maximum, D = 4 m
Free board: 0.30 – 0.50 m
Sludge zone depth: up to 1m

Types of sedimentation tank:

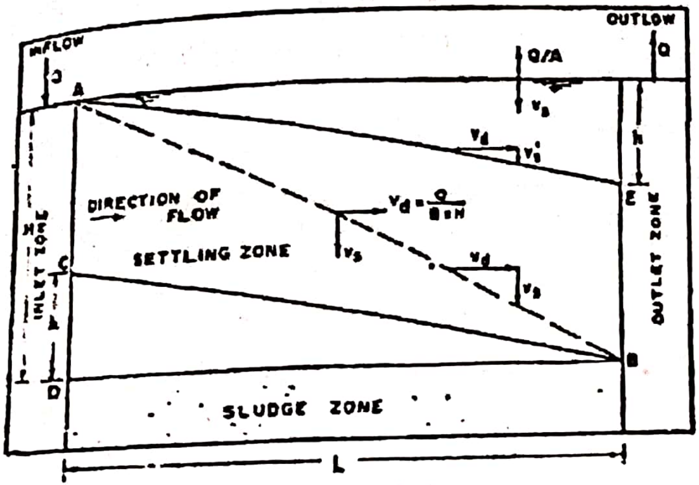
Detention period (t) of a settling tank may be defined as average theoretical time required for the water to flow through the tank length. It is that time which would be required by the flow of water to fill the tank if there were no outflows. The retention time usually ranges between 4 to 8 hours for plain sedimentation and 2 to 4 hours when coagulants are used.

$$\text{Detention time t for rectangular tank is} = \frac{\text{Volume of the tank}}{\text{Rate of flow}} = \frac{V}{Q} = \frac{B\,L\,H}{Q}$$

$$\text{Detention time for circular tank} = \frac{D^2\,(0.011D\ + 0.785\ H)}{Q}$$

Where, D = Diameter of the tank
H = Vertical death at wall or side water depth
B and L = Width and length of the rectangular tank respectively

Let L and H be the length and depth respectively of the settling zone. Let B be the width of the tank and Q be the discharge rate. The horizontal discharge velocity v_d is given by,



$$\text{Horizontal flow velocity, } v_d = \frac{Q}{B\,H}$$

$$\text{Time of horizontal flow, } t_0 = \frac{L}{v_d} = \frac{L\,B\,H}{Q}$$

Consider a particle entering the tank to have a vertical falling speed v_s. The time for falling through distance H will be H/v_s. For the particle to reach the bottom before the water leaves the tank, the time of fail should be equal to time of horizontal flow. Hence

$$\frac{H}{v_s} = \frac{L\,B\,H}{Q}$$

From which

$$v_s = \frac{Q}{B\,L} = \frac{Q}{A}$$ Called surface overflow rate (SOR)

From the above two equation,

$$\frac{v_d}{v_s} = \frac{L}{H}$$

And $t_0 = \frac{H}{v_s}$

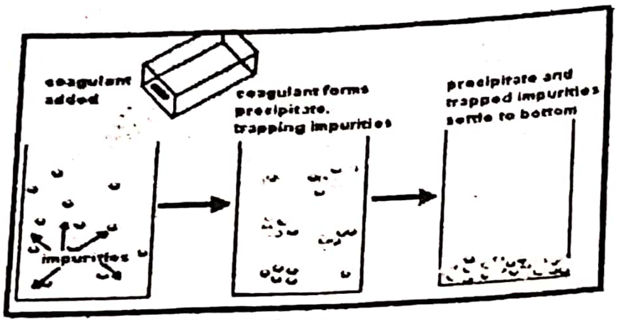
Sedimentation with coagulation: The process of removing fine suspended clay particles as well as colloidal matter in the sedimentation work by using chemicals, which can't be removed by plain sedimentation is called sedimentation with coagulation. The chemicals used for this process is called *coagulants*. These coagulants if properly used, also removes color, odor, taste, bacteria and viruses from water.

Following factors affect coagulation:
- Type of coagulant
- Quantity of coagulant
- Characteristics of water; such as temp., pH, etc.
- Time and method of mixing

Sedimentation with coagulation consists of three different processes:
1. Coagulation: It is the process of mixing coagulants and formation of ppt.
2. Flocculation: It is the process of building up the particles to bigger size called 'floc'.
3. Sedimentation: Bigger floc particles are settled in the tank and are removed; this settling of particles is called sedimentation.

Coagulation and Flocculation: Colloidal particles are difficult to separate from water because they do not settle by gravity and are so small that they pass through the pores of filtration media. To be removed, the individual colloids flocculation & coagulation process commonly used.

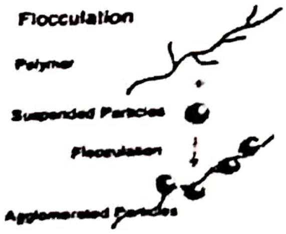
Coagulation: A chemical process that involves a neutralising charge on the particles. This occurs when a coagulant is added to water to destabilise colloidal suspensions. The coagulation and flocculation in water and wastewater treatment processes can be used as a preliminary or intermediary step between other water or wastewater treatment processes like filtration and sedimentation.

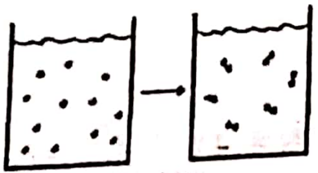


Commonly used coagulants

- Aluminium sulphate or Alum $[Al_2(SO_4)_3.18H_2O]$
- Sodium aluminate $[Na_2Al_2O_3]$
- Chlorinated coppers
- Ferrous sulphate and Lime $[FeSO_4.7H_2O]$
- Magnesium carbonate $[MgCO_3]$

Flocculation: Flocculation is stimulation by mechanical means to agglomerate destabilized particles into compact, fast settleable particles (or flocs). Flocculation or gentle agitation results from velocity differences or gradients in the coagulated water, which causes the fine moving, destabilized particles to come into contact and become large, readily settleable flocs. It is a common practice to provide an initial rapid (or) flash mix for the dispersal of the coagulant or other chemicals into the water. Slow mixing is then done, during which the growth of the floc takes place.





Flocculation

After thoroughly mixing of coagulants in the water, the next operation is flocculation. It is a slow mixing process, which forms floc. Flocculators mostly consist of paddles which are at very slow speed of about 2 – 3 rpm. The detention time for best results should be between 30 and 60 minutes.

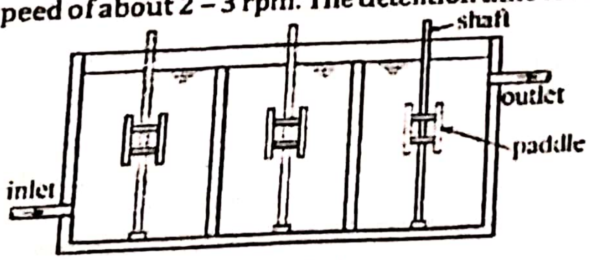


fig: Flocculation

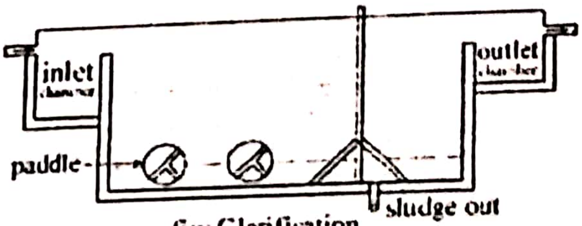
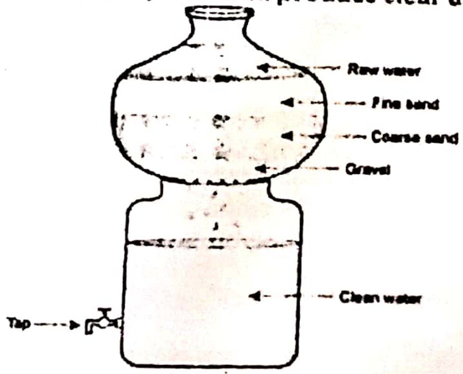


fig: Clarification

Clarification: In this operation the floc which had been formed by flocculation is allowed to settle and is separated from water. For this, water is retained in sedimentation tank for a sufficient period for the settlement of floc to the bottom.

Filtration: The resultant water after sedimentation will not be pure, and may contain some very fine suspended particles and bacteria in it. To remove or to reduce the remaining impurities still further, the water is filtered through the beds of fine granular material, such as sand, etc. The process of passing the water through beds of sand or other granular materials to remove bacteria, color, taste, odor and produce clear and sparkling water is called filtration.



Types of Filter

- Slow sand filter
- Rapid-sand filter

Slow sand filters: These are earliest type of filter and are so called because rate of filtration through them may be 1/20th or less than that of rapid sand filters or pressure filters. Because of low filtration rate, these require more area of land and are costly to install.

Rapid sand filters: These are the most commonly used filter in water supply projects due to their high rate of filtration and other more benefits than the slow sand filter.

Question: Explain the process of coagulation-sedimentation. How does it differ from plain sedimentation? (33th BCS)

Solution:

Sedimentation with coagulation: The process of removing fine suspended clay particles as well as colloidal matter in the sedimentation work by using chemicals, which can't be removed by plain sedimentation is called sedimentation with coagulation. The chemicals used for this process is called coagulants. These coagulants if properly used, also removes color, odor, taste, bacteria and viruses from water.

Following factors affect coagulation:

- Type of coagulant
- Quantity of coagulant

- Characteristics of water; such as temp., pH, etc.
- Time and method of mixing.

Sedimentation with coagulation consists of three different processes:

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2. Flocculation: It is the process of building up the particles to bigger size called 'floc'.
3. Sedimentation: Bigger floc particles are settled in the tank and are removed; this settling of particles is called sedimentation.

Plain sedimentation is the process of removing suspended matters from the water in the tank, so that suspended matter may settle down in the bottom of tank due to gravity. Very fine suspended clay particles are not removed by plain sedimentation. Silt particle of 0.06 mm size requires 10 hours to settle in 3 m deep plain sedimentation tank and 0.02 mm particle will require about 4 days for settling.

This settling time is impracticable, because water cannot be detained for such a long time. In plain sedimentation tanks detention time of about 2 hours for mechanically cleaned basins and about 6 hours for ordinary tanks, can be allowed. When water contains such fine clay particles and colloidal impurities, it becomes necessary to apply such process which can easily remove them from the water.

Question: Write the difference between SSF and RSF. (30th BCS)

Item	Slow Sand Filter	Rapid Sand Filter
Pre treatment	Not required except plain sedimentation	Coagulation, Flocculation and Sedimentation
Base materials	Gravel base of 30 to 75 cm depth with 3 to 65mm size graded gravel.	Gravel base of 45 to 50 cm depth with gravel size varies from 3 to 50 mm in 4 or 5 layers
Filter sand ▪ Effective size ▪ Uniformity coefficient ▪ Thickness of sand bed	 ▪ 0.25 to 0.35 mm ▪ 3 to 5.0 ▪ 80 to 100 cm	 ▪ 0.45 to 0.70 mm ▪ 1.2 to 1.7 ▪ 60 to 75 cm
Under drainage system	Open jointed pipes or drains covered with perforated blocks	Perforated pipe laterals discharging into main header
Size of each unit	50 to 200 sq.m	10 to 100 sq.m
Rate of filtration	100 to 200 Lph/sq.m	4800 to 7200 Lph/sq.m
Cost ▪ Installation ▪ O&M	 ▪ High ▪ Low	 ▪ Low ▪ High
Efficiency ▪ Turbidity of feed water ▪ Removal of bacteria	 Low; < 30 NTU 98 to 99%	 Any level of turbidity of feed water; (with pre-treatment) 80 to 90%
Suitability	For water supply to rural areas and small town	For public water supply to towns and cities
Post treatment	Slight disinfection	Complete disinfection is a must
Ease of construction	Simple	Complicated;
Skilled supervision	Not essential	Essential
Loss of head ▪ Initial ▪ Final	 ▪ 10cm ▪ 80 to 120 cm	 ▪ 30 cm ▪ 250 to 350 cm
Method of cleaning	▪ Scrapping and removing *Schmutzedecke* and 1.5 to 3 cm thick sand layer ▪ Laborious	▪ Back washing with or without compressed air agitation ▪ Simple and easy
Quantity of wash water required	0.2 to 0.5% of total water filtered	1 to 5% of the total water filtered
Cleaning Interval	Three to four months	One to two days

Disinfection: The filtered water may normally contain some harmful disease producing bacteria in it. These bacteria must be killed in order to make the water safe for drinking. The process of killing these bacteria is known as Disinfection or Sterilization. It is necessary to disinfect water to kill bacteria and other micro-organisms, and thus prevent water-borne diseases.

Requirements of Good Disinfectants

- They should destroy all the harmful pathogenic organisms from the water.
- They should not take more time in killing pathogens.
- They should be economical and easily available.
- They should not require high skill for their application.
- After their treatment, the water should not become toxic and objectionable to the user.

Method of Disinfection

- By boiling of water
- By ultra-violet rays
- By the use of Iodine and bromine
- By the use of Ozone
- By the use of excess lime

Question: What is disinfection of water? Write down some methods of it? (MES – 2015)

Solution:

Water disinfection means the removal, deactivation or killing of pathogenic microorganisms. Microorganisms are destroyed or deactivated, resulting in termination of growth and reproduction. When microorganisms are not removed from drinking water, drinking water usage will cause people to fall ill.

For chemical disinfection of water the following disinfectants can be used:

- Boiling of water
- Ultra violet light disinfection
- Disinfection using chlorine
- Ozone water disinfection
- By the use of Iodine and bromine
- By the use of excess lime

Chlorination

The use of chlorine has become practically universal in the disinfection of water. It is cheap, reliable and presents no difficulty in handling.

Question: Why is chlorine used for Disinfection?

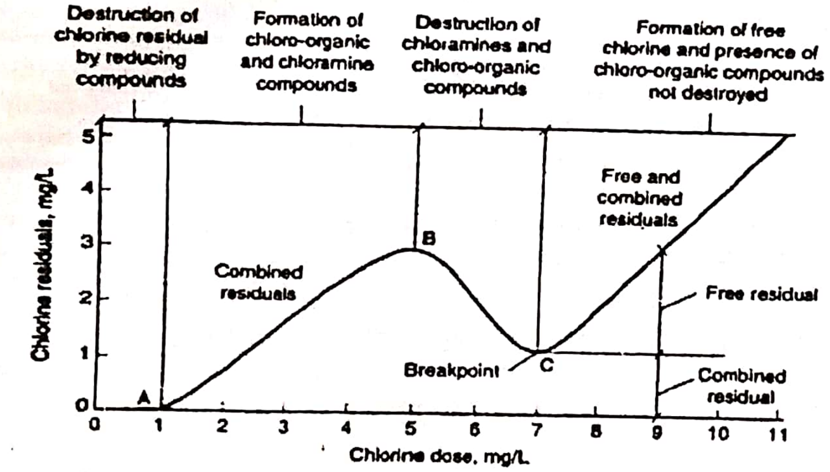
Solution:

Chlorine is one of the most versatile chemicals used in water and wastewater treatment. This powerful oxidizing agent is used for,

1. Available in Liquid, Powder & Gas
2. Removal of ammonia
3. Control of taste and odor
4. Disinfection control of microorganisms
5. Destruction of organic matter
6. Cheap & Easy to use

Breakpoint of Chlorination

When chlorine dose is increased, the combined available residual chlorine also increases. If we further increase the chlorine dose, a sudden drop of residual chlorine occurs and then again increases. Hence, the point where residual chlorine is suddenly dropped and then increased; is called break point chlorination. It completely destroys all the disease bacteria, taste, odor and manganese from water.

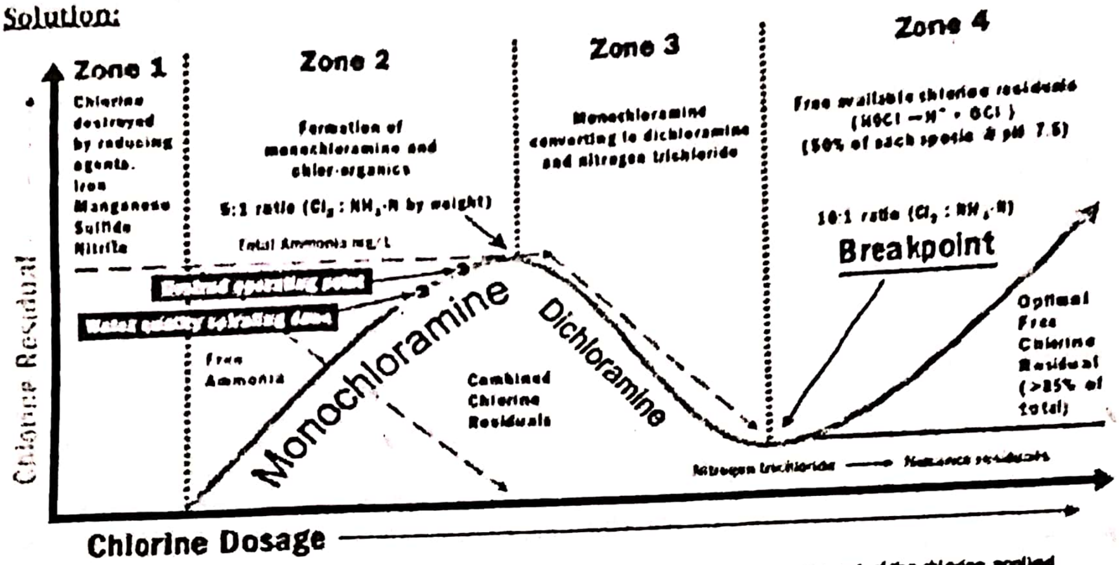


Chlorine reacts with reduced materials (Fe^{2+}, Mn^{2+}, H_2S, organics, NH_3, etc.)

Breakpoint Chlorination

Question: Draw a typical chlorination curve and explain the reaction zones. Explain break-point chlorination. (33th BCS)

Solution:



- **Zone 1:** Initial chlorine demand is caused by reducing agents (Fe^{+2}, Mn^{+2}, H_2S, NO_2^-) that consume most of the chlorine applied
prior to forming combined residuals.

Zone 2: Additional chlorine combines with available total ammonia and reactive organics until forming maximum monochloramine
residual. At the same time, uncombined free ammonia is being depleted until it reaches zero.

Zone 3: More chlorine dosage converts monochloramine into odorous dichloramine and nitrogen trichloride. Total combined
chloramine residual decreases and ammonia concentration approaches zero at the breakpoint.

Zone 4: True free chlorine residual is obtained and provides the least nuisance odor when free residuals make up 85 percent of
the total chlorine concentration. Nuisance combined chlorine residuals survive and the potential for disinfection by-products
(trihalomethane and haloacetic acid) formation remains, as free chlorine residual develops further.

Ammonia (NH_3) and nitrogen-based contaminants like urea get oxidized and become variations of chloramines when combined with chlorine. When ammonia (NH_3) met with hypochlorous acid (HOCl), chlorine starts replacing hydrogens.

The chemical reaction that creates Monochloramine (NH_2Cl) looks like this:

$2NH_3 + 2HOCl \rightarrow 2NH_2Cl + 2H_2O$

Ammonia + Hypochlorous Acid = Monochloramine + Water

Further chlorination of monochloramine creates Dichloramine ($NHCl_2$):

$2NH_2Cl + 2HOCl \rightarrow 2NHCl_2 + 2H_2O$

Monochloramine + Hypochlorous Acid = Dichloramine + Water

And of course, even further chlorination yields the most noxious of chloramines that off-gasses from pools, Nitrogen Trichloride, aka Trichloramine (NCl_3):

$NHCl_2 + 3HOCl \rightarrow NCl_3 + 3H_2O$

Dichloramine + Hypochlorous Acid = Trichloramine + Water

Finally all Hydrogens have been replaced by chlorides to create Nitrogen Trichloride. When chlorine dose is increased, the combined available residual chlorine also increases. If we further increase the chlorine dose, a sudden drop of residual chlorine occurs and then again increases.

Hence, the point where residual chlorine is suddenly dropped and then increased; is called break point chlorination. It completely destroys all the disease bacteria, taste, odor and manganese from water.

Question: The population of 2005 is 10000 and 2015 is 19500. What is the water demand of 2025? Given water demand is 90 lpcd. Chlorine content of 0.5 mg/L is to be added in water. How much bleaching powder is needed if bleaching powder contains 25% of chlorine? (GTCL – 2016, DESCO – 2015, DPDC – 2019)

Solution:

We know, $P_f = P_p\,(1+r)^n$

Growth rate per decade, $r = \sqrt[n]{\dfrac{P_f}{P_p}} - 1 = \sqrt[10]{\dfrac{19500}{10000}} - 1 = 0.069$

Again, $P_{2025} = P_{2015}\,(1+r)^n = 19500\,(1+0.069)^{10} = 38002$

Water demand $= 38002 \times 90 = 3420180$ l/day

Amount of chlorine required per day $= \dfrac{3420180 \times 0.5}{1000 \times 1000} = 1.57$ kg

Bleaching powder required $= \dfrac{1.57 \times 100}{25} = 6.28$ kg

Question: 100 MLD water is to be supplied from a water treatment plant which containing 0.4 ppm Cl_2, if bleaching powder contains 25% available chlorine by weight find out the amount of bleaching powder in kg/day. (DPDC – 2014, RPGCL – 2017, BWDB – 2018, DTCA – 2018, BCIC – 2019)

Solution:

Waste water to be treated = 100 Mld = 100000000 L/day

Amount of chlorine required per day $= \dfrac{100000000 \times 0.4}{1000 \times 1000} = 40$ kg

Amount of bleaching powder required $= \dfrac{40 \times 100}{25} = 160$ kg

Question: 500 m^3/d water is to be supplied from a water treatment plant with chlorine concentration of 0.5 mg/L, if bleaching powder that is used for chlorine has contains 30% available Cl_2 (by weight), find out the amount of bleaching powder in kg/day. (ERL – 2017, DESCO – 2019)

Solution:

Quantity of water to be treated $= 500\ m^3/d = 500 \times 10^3$ L/day

Amount of chlorine required per day $= \dfrac{0.5 \times 500 \times 10^3}{1000 \times 1000} = 0.25$ kg

Amount of bleaching powder required $= \dfrac{0.25 \times 100}{30} = 0.83$ Kg

Question: Bleaching powder এ 30% Chlorine থাকে। 0.5 mg/L ডোজের 4 million litter পানিতে treat করতে কি পরিমাণ bleaching powder লাগবে ?(IIED – 2020)

Solution:

Waste water to be treated = 4 Mld = 4000000 L/day

Amount of chlorine required = $\frac{4000000 \times 0.5}{1000 \times 1000} = 2$ kg

Amount of bleaching powder required = $\frac{2 \times 100}{30} = 6.67$ kg

Question: How many kilograms of bleaching powder with 30% of available chlorine will be required to treat 4 million liters of water with a dosage of 0.5 mg/lit? (30th BCS)

Solution:

Waste water to be treated = 4 ML = 4000000 L

Amount of chlorine required = $\frac{4000000 \times 0.5}{1000 \times 1000} = 2$ kg

Amount of bleaching powder required = $\frac{2 \times 100}{30} = 6.67$ kg

Question: It is required to disinfectant 500,000 gpd of water with 0.3 mg/l of chlorine. If bleaching powder that contains 33.33% of available chlorine is used, how much bleaching powder is needed to treat the daily flow of water. (38th BCS)

Solution:

Average daily water demand = 500000 gpd = 500000 x 3.78 = 1890000 lpd

Amount of chlorine required per day = $\frac{1890000 \times 0.3}{1000 \times 1000} = 0.567$ kg

Amount of bleaching powder required = $\frac{0.567 \times 100}{33.33} = 1.70$ kg.

Question: It is required to disinfect 500000 gpd of water with 0.3 mg/L chlorine. If bleaching powder is used (which contains 25% of available chlorine), how many kg of bleaching powder are needed to treat the daily flow of water? (WRGCL – 2014)

Solution:

Average daily water demand = 500000 gpd = 500000 x 3.78 = 1890000 lpd

Amount of chlorine required per day = $\frac{1890000 \times 0.3}{1000 \times 1000} = 0.567$ kg

Amount of bleaching powder required = $\frac{0.567 \times 100}{25} = 2.268$ kg.

Question: A slow sand filtration unit is producing 1500 m³ of water/day. How much bleaching powder with 30% available chlorine will be required per day to treat this water with a chlorine dose 0.5 mg/L. (34th BCS)

Solution:

Quantity of water to be treated = 1500 m³/d = 1.5×10^6 L/day

Amount of chlorine required per day = $\frac{0.5 \times 1.5 \times 10^6}{1000 \times 1000} = 0.75$ kg

Amount of bleaching powder required = $\frac{0.75 \times 100}{30} = 2.5$ Kg

Question: A water treatment plant produces 1 ML waste water per day. Bleaching powder (40% Cl_2) is used to disinfect the water in this plant. You must maintain 0.5 mg/L Cl_2 residual in the finished water with a Cl_2 demand of 3.5 mg/L. Calculate the amount of bleaching powder required per day (EGCB – 2020)

Solution:

Waste water to be treated = 1 MLD = 1000000 lpd

Chlorine dosage = chlorine demand + residual chlorine = 0.5 + 3.5 = 4 mg/L

Amount of chlorine required per day = $\frac{1000000 \times 4}{1000 \times 1000} = 4$ kg/day

Amount of bleaching powder required = $\frac{4 \times 100}{40} = 10$ kg/day

Question: 1000 L of water is contaminated with 25 mg/L toxic substances. Concentration of toxic substances is to be reduced to 0.5 mg/L be discharging. Determine the mass of toxic substances to be reduced? (SGFCL – 2017)

Solution:

Mass of toxic substances to be reduced = (25 – 0.5) x 1000 = 24500 mg = 24.5 g

Water softening: The removal or reduction of hardness from the water is known as water softening. It requires more consumption of soap in producing lather for washing clothes with hard water than soft water. The main advantage of water softening is reduction in the consumption of soap.

Necessity

- Hard water caused following problems, hence it is essential to remove from water.
- It causes more consumption of soap during washing of clothes.
- It causes formation of scales on the boilers and other hot water heating system.
- It causes choking and clogging problems of house plumbing.

Aeration: It is the process of bringing water in intimate contact with air (O_2), which absorbs oxygen from air and remove CO_2 gas, iron, manganese, etc.

Objective

- To remove taste and odor.
- To increase the dissolved oxygen in water.
- To remove H_2S, iron and manganese up to certain extent.
- To decrease the CO_2 in water. (Which may be up to 70%)

Question: Why removal of turbidity is essential to effective disinfection? (BPDB – 2015)

Solution:

Disinfection is usually accomplished by means of chlorine, ozone and chlorine oxide. To be effective there must be a contact between the agent and the organisms to be killed. But many of the pathogenic organisms may be encased in the particles that causes turbidity and get protected from the disinfectant. That's why removal of turbidity is essential to effective disinfection.

Question: Flow diagram of conventional activated sludge process?
(PGCL – 2017, BCPCL – 2016, BPDB – 2018)

Solution:

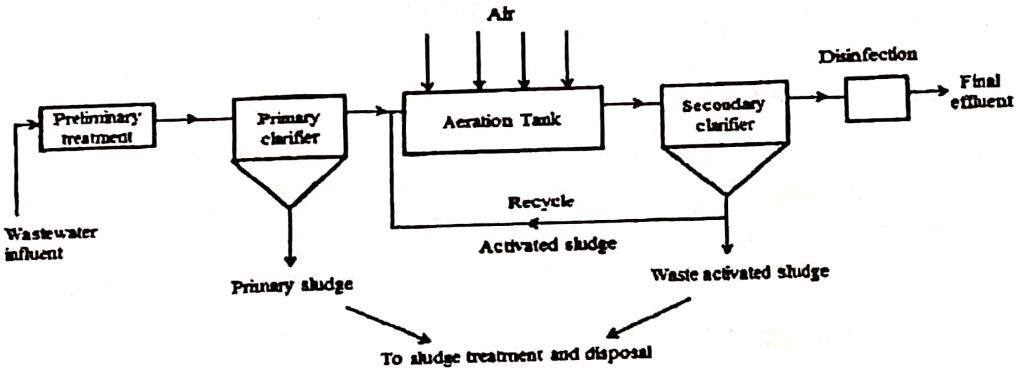
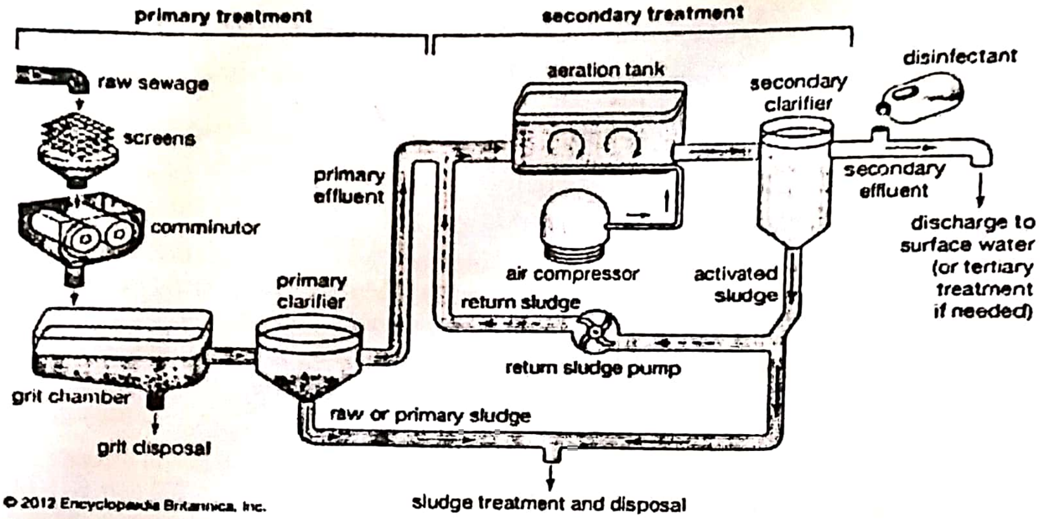


Fig. 4 - Flow diagram of activated sludge wastewater treatment system

Question: Why aeration is necessary in waste water treatment process? (PGCB – 2017)

Solution:

Wastewater aeration is the process of adding air into wastewater to allow aerobic bio-degradation of the pollutant components. In municipal and industrial wastewater treatment, aeration is part of the stage known as the secondary treatment process. The activated sludge process is the most common option in secondary treatment. Aeration in an activated sludge process is based on pumping air into a tank, which promotes the microbial growth in the wastewater. The microbes feed on the organic material, forming flocs which can easily settle out. After settling in a separate settling tank, bacteria forming the "activated sludge" flocs are continually re-circulated back to the aeration basin to increase the rate of decomposition. An ample and evenly distributed oxygen supply in an aeration system is the key to rapid, economically-viable and effective wastewater treatment.



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Question: What is the pre mechanism by which heavy metal ions are removed during coagulation process? (DPDC – 2019)

Solution:

Chemical coagulation process is considered to be a valid method which is determined by the hydrolyzed species of the inorganic coagulants under different raw water and coagulation conditions. And the main mechanisms of the removal of heavy metals are adsorption, complexation, and coprecipitation. Compared with the aluminum-based coagulants, the iron-based coagulants have better performance due to the use of wide pH range and large surface area of the resulting flocs. During the chemical coagulation process, the valence state of arsenic and antimony could affect the removal efficiency. Thus, the oxidants and reductants are often combined with inorganic coagulants used in this process. It is found that pH is an important factor greatly influencing the performance directly or indirectly. The complex resulting from the interaction between the inorganic/organic pollutant and inorganic coagulant may contribute to the removal of heavy metals. Overall, chemical coagulation is an effective way to control heavy metal pollution with/without other water treatment technologies.

Question: Waste water is flowing through a horizontal grit chamber at a maximum flow rate 30 ft^3/s. The depth of grit chamber is 6 ft and length is 15 times of its width. If the approach velocity is 1ft/sec, determine the length of grit chamber. (EGCB – 2020, CPGCBL – 2021)

Solution:

Maximum flow rate $= 30\ ft^3/s$
Horizontal velocity, $V_H = 1$ ft/s
Assume, Width of the grit chamber $= B$
Length of the grit chamber, $L = 15B$
Depth of the grit chamber, $H = 6$ ft
Area of grit chamber, $A = \frac{Q}{V_H}$

$$B \times H = \frac{30}{1}$$
$$B \times 6 = 30$$
$$B = 5 \text{ ft}$$

Length of grit chamber, $L = 15 \times 5 = 75$ ft

Question: A rectangular settling tank without mechanical equipment is to treat 1 million of raw water per day. If the design criteria are that the detention period is 2.5 hours, the velocity of flow is 8 cm/minutes and depth of water and sediment is 4.5 m. then what would be (i) The length of the tank? (ii) The width of the tank if an allowance of 1.5 m is to be made for sediment? (iii) Overflow rate of the tank?

Solution:

Discharge, $Q = 10^6$ litres per day $= 41.67\ m^3/hr = 0.6945\ m^3/min$
Detention period, $t = 2.5$ hours
Velocity of flow, $v_d = 8$ cm/min
Depth of water and sediment = 4.5 m
Length of tank, $L = v_d \times t = 8 \times 10^{-2} \times 2.5 \times 60 = 12$ m
When an allowance of 1.5 m is made for sediment, the depth of water, H = 4.5 – 1.5 = 3 m

$$v_d = \frac{Q}{B\,H}$$
$$B = \frac{Q}{H \times v_d} = \frac{0.6945}{3 \times 8 \times 10^{-2}} = 2.9 \text{ m}$$
$$\text{Overflow rate} = \frac{Q}{B\,L} = \frac{41.67}{2.9 \times 12} = 1.1974\ m^3/hr/m^2$$

Question: If the flow of water supply is 1023 m^3/day and volume of this tank is 93 m^3. Determine detention period of this tank. (DPDC – 2014)

Solution:

$$\text{Detention time, } t = \frac{\text{Volume}}{\text{Discharge}} = \frac{93}{1023} = 0.09091 \text{ day} = 2.18 \text{ hr}$$

Question: In 300 m³ sedimentation tank water is flowing in at rate 1000 m³/day. What is the detention time in hours? (NPCBL – 2017, GTCL – 2018)

Solution:

$V = 300\ \text{m}^3, Q = 1000\ \text{m}^3/\text{day} = 41.67\ \text{m}^3/\text{hr}$

Detention time, $t = \frac{V}{Q} = \frac{300}{41.67} = 7.2\ \text{hr}$

Question: Design a rectangular sedimentation tank to treat 2.4 million liters of raw water per day. The detention period may be assumed to be 3 hours.

Solution:

Raw water flow per day is 2.4 x 10^6 liters. Detention period is 3h.

Volume of tank = Flow x Detention period = $2.4 \times 103 \times \frac{3}{24} = 300\ \text{m}^3$

Assume, depth of tank = 3.0 m.

Surface area $= \frac{300}{3} = 100\ \text{m}^2$

Assume, $L/B = 3, L = 3B$

$3B^2 = 100\ \text{m}^2$ *i.e.* $B = 5.8\ \text{m}$

$L = 3B = 5.8 \times 3 = 17.4\ \text{m}$

Question: One million gallon liters of water (1 mgd) flows through a sedimentation tank. If the size of the tank is 20' x 50' x 10', find the detention time of the tank (BPDB – 2016, CPGCBL – 2018)

Solution:

Volume of the tank $= \frac{20 \times 50 \times 10 \times 1000}{3.28 \times 3.28 \times 3.28} = 2.833 \times 10^5\ L$

Detention time, $t = \frac{\text{Volume of the tank}}{\text{Flow per unit time}} = \frac{2.833 \times 10^5}{1 \times 10^6 \times 3.78} = 0.0749\ \text{day} = 1.79\ \text{hours}$

Solution: One million gallon liters of water (1 mgd) flows through a sedimentation tank. If the size of the tank is 20' x 50' x 10', find the detention time of the tank. (CPGCBL – 2018)

Solution:

We know, Detention time, $t = \frac{\text{Volume of the tank}}{\text{Flow per unit time}}$

Volume of the tank $= \frac{20 \times 50 \times 10 \times 1000}{3.28^3} = 2.833 \times 10^5\ \text{L}$

Detention time, $t = \frac{2.833 \times 10^5}{1 \times 10^6 \times 3.78} = 0.0749\ \text{day} = 1.79\ \text{hours}$

Solution: A rectangular grit chamber is designed to remove particles with a dia of 0.2 mm and sp. gravity 2.65. Settling velocity of these particles has been found to be 0.02 m/s. A flow through velocity of 0.3 m/s shall be maintained through a proportional weir. Determine the tank dimensions for a max water flow of 10000 m³/day

Solution:

Discharge, $Q = 10000\ \text{m}^3/\text{day} = 0.116\ \text{m}^3/\text{s}$

Settling velocity, $V_s = 0.02\ \text{m/s}$

Flow velocity, $V_d = 0.3\ \text{m/s}$

So cross sectional area $= \frac{Q}{V_d} = \frac{0.116}{0.3} = 0.385$ sq m.

Provide effective depth = 1.0 m, the width of tank = 0.385/1 = 0.385 m

Surface loading = 0.116/0.02 = 5.8 m³/m²/day

Length of the chamber = 5.8/0.385 = 15 m

Overall depth = 1.0 + 0.3 m (distance to crest of weir) + 0.45 free board = 1.75 m

Tank dimensions = 15 x 0.385 x 1.75 m deep

Check $DT = \frac{15 \times 0.385 \times 1.0}{0.116} = 50$ sec

Solution: A water treatment plant has a flow rate of 0.6 m³/sec. The settling basin at the plant has an effective settling volume that is 20 m long, 3 m tall and 6 m wide. Will particles that have a settling velocity of 0.004 m/sec be completely removed? If not, what percent of the particles will be removed? (SGFL – 2021)

Solution:

$v_0 = \frac{Q}{A} = \frac{0.6}{20 \times 6} = 0.005\ \text{m/sec}$

Since v_0 is greater than the settling velocity of the particle of interest, they will not be completely removed.

Percent removed $= \frac{v_p}{v_0} = \frac{0.004}{0.005} \times 100 = 80\%$

Question: The maximum daily demand at a water purification plant has been estimated as 12 million liters per day. Design the dimensions of a suitable sedimentation tank for the raw supplies, assuming a detention period of 6 hours and the velocity of flow as 20 cm per minute.

Solution:

Maximum daily demand = 12×10^6 liters

Quantity of water to be treated during the detention period of 6 hours $= \frac{12 \times 10^6 \times 6}{24}$

$= 3 \times 10^6$ liters

= 3000 cubic metres

The capacity of the tank = 3000 cu. m.

Velocity of flow to be maintained through the tank = 20 cm/minute = 0.2 m/minute

The length of the tank required = velocity of flow x detention period

$$\text{Cross sectional area of the tank required} = \frac{\text{Capacity of the tank}}{\text{Length of the tank}} = \frac{3000}{72}$$

$$= 41.67\ m^2 = 41.7\ m^2$$

Assuming the water depth in the tank as 4 m,

$$\text{The width of the tank required} = \frac{41.7}{4} = 10.42\ m, \text{ say } 10.5\ m$$

Using free board of 0.5 m, the overall depth = 0.5 + 4 = 4.5 m

Hence, Size of the tank = 72 m x 10.5 m x 4.5 m

Question: A rectangular settling tank without mechanical equipment is to treat 1.8 million litres per day of raw water. The sedimentation period is to be 4 hours, the velocity of flow 8 cm/minute and the depth of the water and sediment 4.2 m. If an allowance of 1.2 m for sediment is made, what should be the length of the basin and the width of the basin?

Solution:

Maximum daily demand = 1.8 x 10^6 litres = 1800 cubic meters

$$\text{The capacity of the tank} = \frac{1800 \times 4}{24} = 300\ \text{cu. m.}$$

Flow velocity = 8 cm/minute

Length of the tank = Flow velocity x Detention time = 8 x 4 x 60 = 1920 cm = 19.2 m

$$\text{The cross sectional area of the tank} = \frac{\text{Capacity of the tank}}{\text{length of the tank}} = \frac{300}{19.2} = 15.63\ m^2$$

The depth of sediment and water = 4.2 m

The depth of sediment = 1.2 m

The water depth = 3 m

$$\text{The width of the tank} = \frac{\text{Cross sectional area}}{\text{water depth}} = \frac{15.63}{3} = 5.21\ m\ (5.20\ m\ \text{say})$$

Question: A circular sedimentation tank fitted with standard mechanical sludge removal equipment is to handle 3.5 million liters per day of raw water. If the detention period of the tank is 5 hours, and the depth of the tank is 3 m, what should be the diameter of the tank?

Solution:

Quantity of the raw water to be treated per day = 3.5 x 10^6 liters

$$\text{The capacity of the tank} = \frac{3.5 \times 10^6 \times 5}{24} = 728 \times 103\ \text{liters} = 728\ \text{cu. m}$$

The capacity of a circular tank of depth H and diameter D is given by

Volume $= D^2\ [0.011\ D\ + 0.785\ H]$

Here, $H = 3$ m (given)

$728 = D^2\ (0.011D + 0.785 \times 3)\ =\ D^2(0.011\ D + 2.255)$

Solving this equation, $D = 17.3$ m

Question: Design a six slow sand filter beds from the following data:
Population to be served = 50000 persons
Per capita demand = 150 liters /head/day
Rate of filtration = 180 liters/hour/sq. m
Length of each bed = Twice the breadth
Assume maximum demand as 1.8 times the average daily demand. Also assume that one unit out of six will be kept as stand by.

Solution:

Average daily demand = Population x Per capita demand = 50,000 x 150 liters/day

= 7.5 x 106 liters/day

Maximum daily demand $= 1.8 \times 7.5 \times 10^6\ = 13.5 \times 10^6$ liters/day

Rate of filtration per day = (180 x 24) liters/sq. m/day

$$\text{Total surface area of filters required} = \frac{\text{Max. daily demand}}{\text{Rate of filtration per day}} = \frac{13.5 \times 10^6}{180 \times 24} = 3125\ \text{sq. m}$$

Now, six units are to be used, out of them, one is to be kept as stand-by, and hence only 5 units should provide the necessary area of filter required.

$$\text{The area of each filter unit} = \frac{1}{5} \times \text{Total area reqd.} = \frac{1}{5} \times 3125 = 625\ \text{sq. m.}$$

Now, if L is the length and B is the breadth of each unit, then $L\ =\ 2\ B$ (given)

$2B \times B\ =\ 625$ sq. m

$B^2 = 312.5$ sq. m

$B\ = 17.7$ m say 18 m

$L = 2 \times 17.75 =\ 36$ m

Hence, use filter units with one unit as stand by, each unit of size 36m x 18m, arranged in series with 3 units on either side.

Question: What is acid rain? What are the impacts of acid rain? (WASA – 2014, RRI – 2015)

Solution:

Acid deposition, more commonly known as acid rain, results from man-made emissions of Sulphur dioxide and nitrogen oxides through the burning of fossil fuels for energy and transportation. Acid rain has negative effects on the environment in which we live. Since acid rain is a trans-boundary pollution problem, if large quantities of acid rain are deposited they may have detrimental consequences for wildlife, trees, soils, freshwater, and buildings.

Impacts of acid rain

- Harms fish and wild life.
- Harms plants and trees
- Causes discoloration of building paints.
- Causes corrosion of metals and metallic materials.

Question: Write down the effect of climate change in Bangladesh (DPDC – 2014)

Solution:

More than three-quarters or 13.4 crore of around 16.5 crore population of Bangladesh are at the risk of declining living standards as a result of rising temperature and erratic rainfall due to climate change, the World Bank has said. Rising temperature could affect living standards in diverse ways. Top among them are fall in agricultural and labour productivity and rise in spread of vector-borne and other infectious diseases resulting in lost productivity and income

Climate change impact

- Loss of GDP 6.7pc or $171 billion by 2050.
- Temperature increase projected up to 2.5 degree by 2050.
- Chattogram, Barishal, Dhaka and Khulna division's worst affected.
- Hill districts ae included as new hotspots.
- Climate change affecting livelihood, health and production.

Question: Write the name of major greenhouse gases.
(PGCB – 2018, DTCA – 2018, NHA – 2019, DPDC – 2019)

Solution:

- Water vapor (H_2O)
- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Ozone (O_3)
- Chlorofluorocarbons (CFCs)

Question: From which harmful ray's stratospheric ozone layer save us? Which substances harm ozone layer? Write down the problems behind ground-water exploration in BD. (BWDB – 2018)

Solution:

The ozone layer absorbs ultraviolet radiation rays and prevents them from coming to the surface of the earth thus saving the human beings from harmful rays. Halocarbon refrigerants, solvents, propellants and foam-blowing agents [chlorofluorocarbons (CFCs), HCFCs, halons] referred to as ozone-depleting substances (ODS).
Bangladesh is a country of rivers and floods but groundwater is still a vital resource because it provides bacterially safe water and helps produce food for millions of people. Availability of groundwater has not been a constraint to agricultural development. But this resource is increasingly facing various problems including quality hazards in many areas where the exposure to pollution from agriculture, urbanized areas and industrial sites as well as arsenic contamination in shallower groundwater aquifers makes the water unfit for human consumption and in some cases even for irrigation purposes. High rates of pumping for irrigation and other uses from the shallow aquifers in coastal areas may result in widespread saltwater intrusion, downward leakage of arsenic concentrations and the general degradation of water resources. Besides, use of agrochemicals may cause contamination of shallow groundwater and sediments. Continuous decline of groundwater tables due to over-withdrawal has also been reported from some areas. Thus the overall situation calls for urgent groundwater management for sustainable development. Groundwater management must adopt an integrated approach taking into account a wide range of ecological, socio-economic and scientific factors and needs.

Question: What are the main problem for extraction of ground water and collection of surface water in Bangladesh? (DPDC – 2019)

Solution:

Bangladesh is a country of rivers and floods but groundwater is still a vital resource because it provides bacterially safe water and helps produce food for millions of people. Availability of groundwater has not been a constraint to agricultural development. But this resource is increasingly facing various problems including quality hazards in many areas where the exposure to pollution from agriculture, urbanized areas and industrial sites as well as arsenic contamination in shallower groundwater aquifers makes the water unfit for human consumption and in some cases even for irrigation purposes. High rates of pumping for irrigation and other uses from the shallow aquifers in coastal areas may result in widespread saltwater intrusion, downward leakage of arsenic concentrations and the general degradation of water resources. Besides, use of agrochemicals may cause contamination of shallow groundwater and sediments. Continuous decline of groundwater tables due to over-withdrawal has also been reported from some areas. Thus the overall situation calls for urgent groundwater management for sustainable development. Groundwater management must adopt an integrated approach taking into account a wide range of ecological, socio-economic and scientific factors and needs.

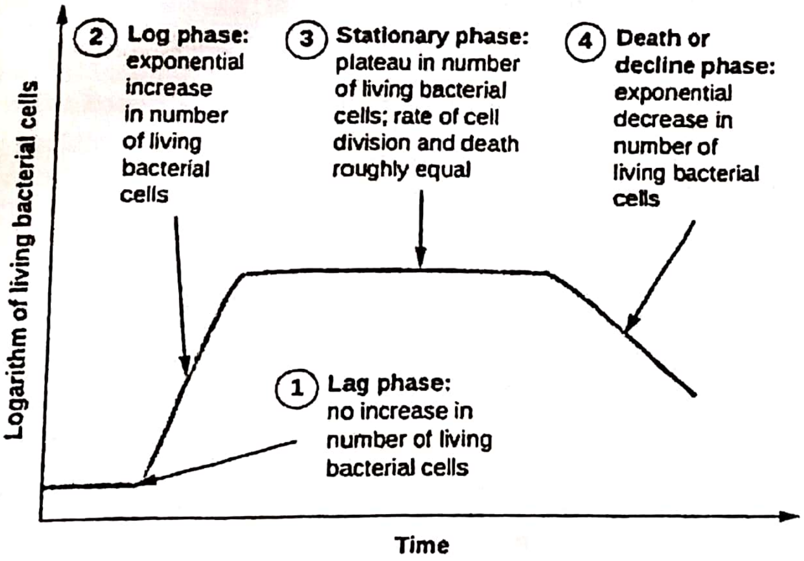
Surface waters receive pollutants from agricultural, industrial, domestic and municipal sources. Concentration of silt content in turbulent water in the monsoon is high. Similarly algal growth in stagnant water bodies in the dry season is also very high. Insanitary practices of people have greatly contributed to the deterioration of quality of surface water sources. The faecal coliform concentration in most surface water sources lies in the range of 500 to several thousand per 100ml. The rivers and surface water sources around densely populated urban areas depending on water quality parameters are four to ten times more polluted than the similar water sources in the countryside. The deterioration of water quality is directly related to population density and industrial activities due to poor management of domestic and industrial wastewater. The use of surface water for drinking purpose requires clarification and disinfection by elaborate treatment processes.

Question: Abbreviations of the words: ETP, STP, ECR, BOD and COD

Solution:

ETP = Effluent Treatment Plant
STP = Sewage Treatment Plant
ECR = Earth Centered Rotating
BOD = Biological Oxygen Demand
COD = Chemical Oxygen Demand

Question: Draw the four phases of bacterial growth.
(BWDB – 2016, RRI – 2015, BUET M. Sc. –2013)



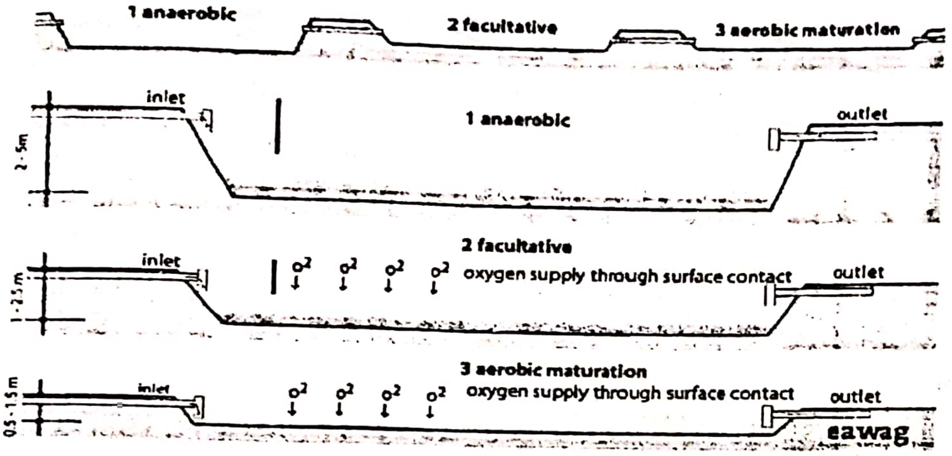
Question: Write down the name and function of the stabilization pond. (RRI – 2014)

Solution:

Waste stabilization ponds are pond built for wastewater treatment where biological processes occur which reduce the organic content (measured as BOD) and kill pathogen in the wastewater. Waste stabilization ponds are commonly used for wastewater treatment in developing countries.

Stabilization ponds may be-

a. Aerobic
b. Anaerobic
c. Facultative



- Aerobic ponds are shallow ponds with depth less than 0.5 m and BOD loading of 40-120 kg/ha.d so as to maximize penetration of light throughout the liquid depth. Such ponds develop intense algal growth.
- Anaerobic ponds are used as pretreatment of high strength wastes with BOD load of 400-3000 kg./ha.d. Such ponds are constructed with a depth of 2.5-5m as light penetration is unimportant.
- Facultative pond functions aerobically at the surface while anaerobic conditions prevail at the bottom. They are often about 1 to 2 m in depth. The aerobic acts as a good check against odor evaluation from the pond.

Question: Explain the biological treatment process of sewage. (30th BCS)

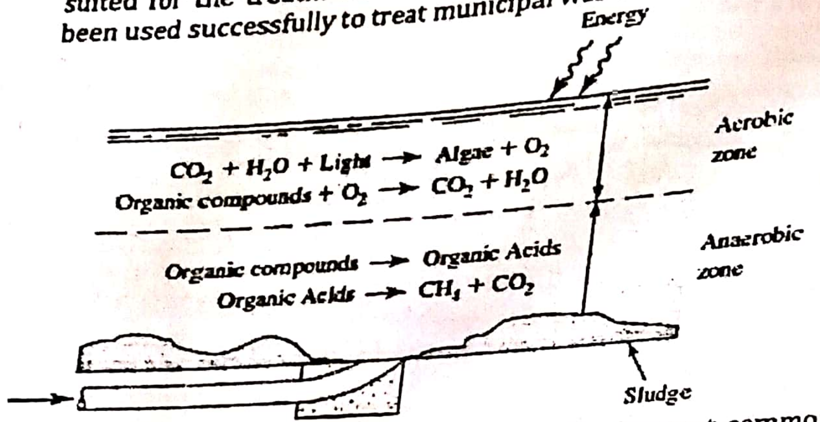
Solution:

Treatment ponds have been used to treat wastewater for many years, particularly as wastewater treatment systems for small communities. Waste stabilization pond has been used as an all-inclusive term that refers to a pond or lagoon used to treat organic waste by biological and physical processes.

Aerobic Ponds. The aerobic pond is a shallow pond in which light penetrates to the bottom, thereby maintaining active algal photosynthesis throughout the entire system. During the daylight hours, large amounts of oxygen are supplied by the photosynthesis process; during the hours of darkness, wind mixing of the shallow water mass generally provides a high degree of surface reaeration. Stabilization of the organic material entering an aerobic pond is accomplished mainly through the action of aerobic bacteria.

Anaerobic Ponds. The magnitude of the organic loading and the availability of dissolved oxygen determine whether the biological activity in a treatment pond will occur under aerobic or anaerobic conditions. A pond may be maintained in an anaerobic condition by applying a BOD_5 load that exceeds oxygen production from photosynthesis. Photosynthesis can be reduced by decreasing the surface area and increasing the depth. Anaerobic ponds become turbid from the presence of reduced metal sulfides. This restricts light penetration to the point that algal growth becomes negligible.

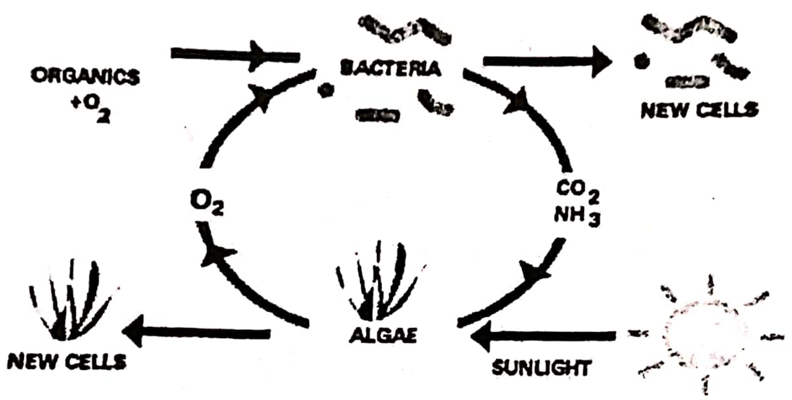
Anaerobic treatment of complex wastes involves three stages. In the first stage organic matter is hydrolyzed. In the second stage (known as acid fermentation), complex organic materials are broken down mainly to short-chain acids and alcohols. In the third stage (known as methane fermentation), these materials are converted to gases, primarily methane and carbon dioxide. The proper design of anaerobic ponds must result in environmental conditions favorable to methane fermentation. Anaerobic ponds are used primarily as a pretreatment process and are particularly suited for the treatment of high-temperature, high-strength wastewaters. However, they have been used successfully to treat municipal wastewaters as well.

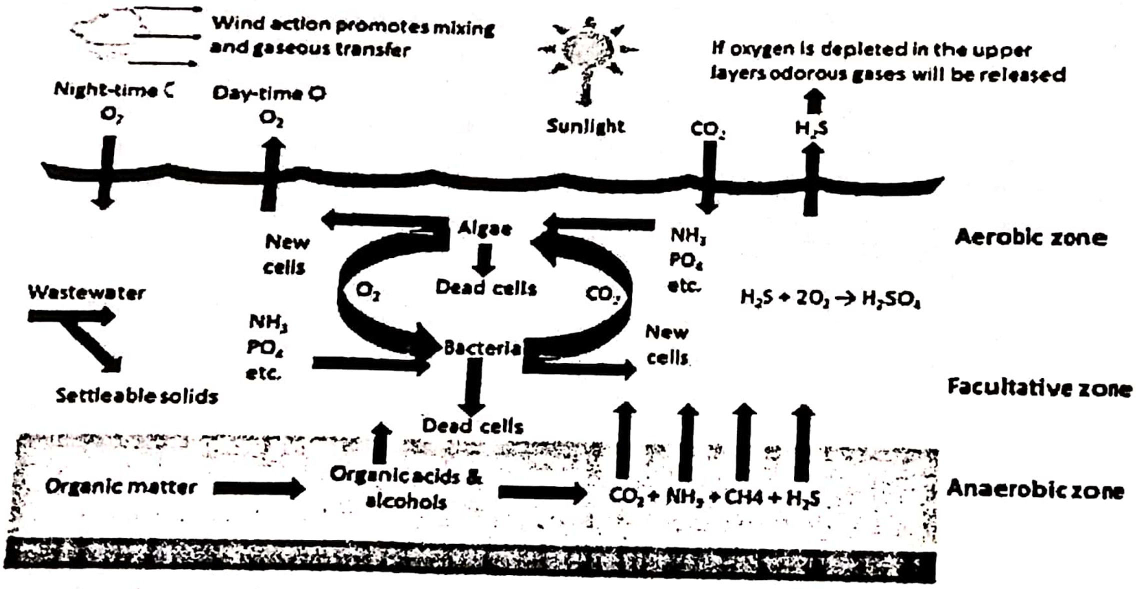


Facultative Ponds. Facultative ponds are by far the most common type wastewater treatment systems for small communities. Facultative ponds are popular for such treatment situations because long retention times facilitate the management of large fluctuations in wastewater flow and strength with no significant effect on effluent quality. Also capital, operating, and maintenance costs are less than those of other biological systems that provide equivalent treatment. Suspended solids contained in the wastewater settle to the pond bottom, where an anaerobic layer develops. The facultative zone exists just above the anaerobic zone. This means that molecular oxygen will not be available in the region at all times. Generally, the zone is aerobic during the daylight hours and anaerobic during the hours of darkness.

Question: Draw mutualism diagram of algae bacteria in waste stabilization pond?

Solution:





Biochemical oxygen demand (BOD) & Chemical Oxygen Demand (COD)

The amount of oxygen required to oxidize a substance to carbon dioxide and water may be calculated by stoichiometry if the chemical composition of the substance is known. This amount of oxygen is known as the theoretical oxygen demand ($ThOD$).

Oxygen demand of wastes measured by

1. Biochemical Oxygen Demand (BOD)
2. Chemical Oxygen Demand (COD)

The amount of oxygen required by microorganisms to oxidize organic wastes aerobically is called the biochemical oxygen demand (BOD). Expressed in milligrams of oxygen per liter of wastewater (mg/L). The BOD is made up of two parts: the carbonaceous oxygen demand ($CBOD$) and the nitrogenous oxygen demand ($NBOD$).

The five-day BOD or BOD_5 is the total amount of oxygen consumed by microorganism during the first five days of biodegradation.

$$BOD_5 = \frac{DO_i - DO_f}{P}$$

Where, DO_i = the initial dissolved oxygen (DO) of the diluted wastewater.

DO_f = The DO of the diluted wastewater, 5 days later.

$$P = \text{the dilution fraction} = \frac{\text{volume of wastewater}}{\text{volume of wastewater plus dilution water}}$$

A standard BOD bottle holds 300 mL, so P is just the volume of wastewater divided by 300 mL

<u>For seeded dilution water</u>

$$BOD_m V_m = BOD_w V_w + BOD_d V_d$$

BOD_m = BOD of the mixture of wastewater and seeded dilution water
BOD_w = BOD of the wastewater alone
BOD_d = BOD of the seeded dilution water alone
V_w = the volume of wastewater in the mixture
V_d = the volume of seeded dilution water in the mixture
V_m = the volume of the mixture = $V_d + V_w$

$$BOD_5 = \frac{BOD_m - BOD_d\,(1 - P)}{P}$$

$BOD_m = DO_i - DO_f$ and $BOD_d = B_i - B_f$

B_i = initial DO in the seeded dilution water

B_f = final DO in the seeded dilution water

BOD of the waste itself,

$$BOD_m = \frac{(DO_i - DO_f) - (B_i - B_f)(1 - P)}{P}$$

Modeling BOD as first order reaction

If we let L_t represents the amount of oxygen demand left after time t then assuming first order reaction we can write,

$$\frac{dL_t}{dt} = -k\,L_t$$

$$L_t = L_0\,e^{-kt}$$

The ultimate carbonaceous oxygen demand is the sum of the amount of oxygen consumed by the waste in the first t days BOD_t, plus the amount of oxygen remaining to be consumed after time t.

$$L_0 = BOD_t + L_t$$

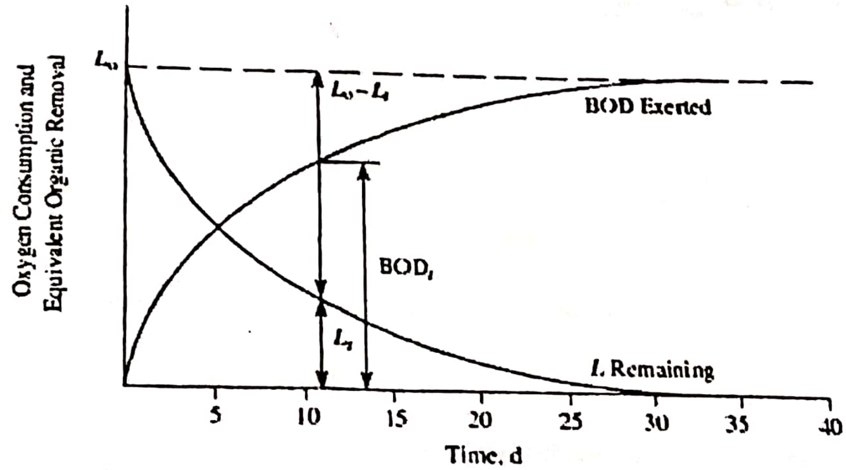
$$BOD_t = L_0\,(1 - e^{-kt})$$

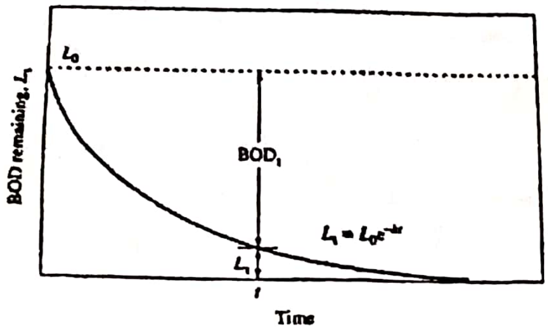
BOD equation for base 10,

$$BOD_t = L_0\,(1 - 10^{-kt})$$

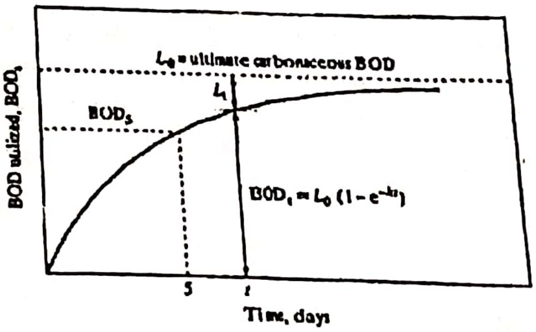
Note that lower case *k* is used for the reaction rate constant in base *e* and that capital *K* is used for the constant in base 10.

$$k = K\ \ln 10 = 2.303\,K$$





(a) BOD remaining



(b) BOD utilized

The oxygen needed to oxidize organic carbon to carbon dioxide is called the carbonaceous oxygen demand ($CBOD$) and the oxygen needed to convert ammonia to nitrate is called the nitrogenous oxygen demand ($NBOD$).

From this reaction the theoretical NBOD can be calculated as follows:

$$NH_4^+ + 2O_2 \xleftrightarrow{microorganisms} NO_3^- + H_2O + 2H^+$$

$$NBOD = \frac{\text{grams of oxygen used}}{\text{grams of nitrogen oxidized}} = \frac{4 \times 16}{14} = 4.57\ g\ O_2/g\ N$$

The total concentration of organic and ammonia nitrogen in wastewater is known as the total kjeldahl nitrogen or TKN.

Ultimate $NBOD = 4.6 \times TKN$

Temperature: Most biological processes speed up as the temperature increases and slow down as the temperature drops. Because oxygen utilization is caused by the metabolism of microorganisms, the rate of utilization is similarly affected by temperature. BOD rate constant is adjusted to the receiving-water temperature using the following expression,

$$k_T = k_{20}\,\theta^{(T-20)}$$

T = temperature of interest, °C
k_T = BOD rate constant at the temperature of interest, d^{-1}
k_{20} = BOD rate constant determined at 20°C, d^{-1}
θ = temperature coefficient. This has a value of 1.135 for temperatures between 4 and 20°C and 1.056 for temperatures between 20 and 30°C

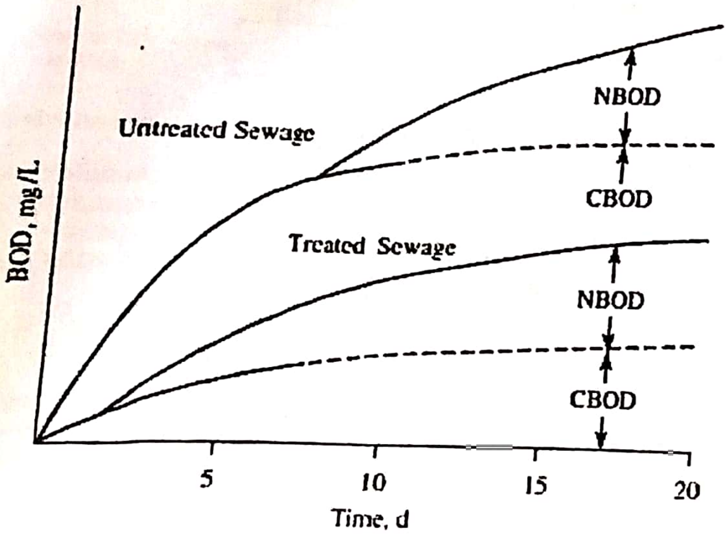


Figure: BOD curves showing both carbonaceous and nitrogenous BOD.

DO Sag Equation

One of the major tools of water quality management in rivers is the ability to assess the capability of a stream to absorb a waste load. This is done by determining the profile of DO concentration downstream from a waste discharge. This profile is called the DO sag curve.

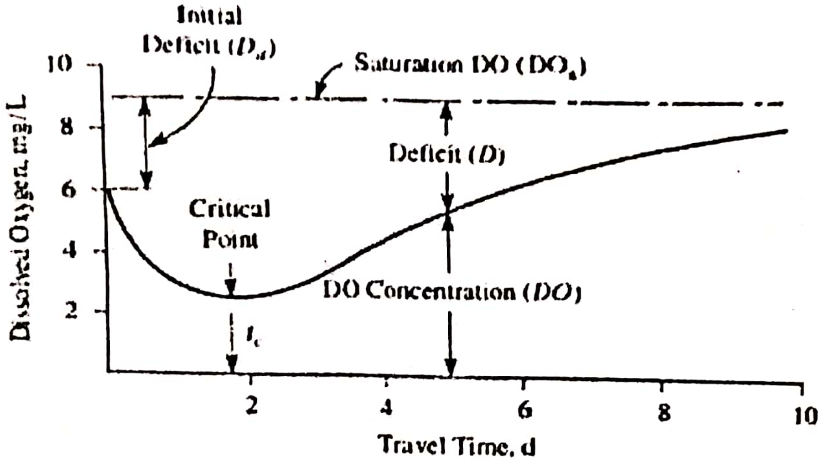


Figure: Typical DO sag curve.

$$\text{Oxygen deficit, } D = \frac{k_d L_0}{k_r - k_d}\left(e^{-k_d t} - e^{-k_r t}\right) + D_0\, e^{-k_r t}$$

D = oxygen deficit in river water after exertion of BOD for time, t, mg/L
L_0 = initial ultimate BOD after river and wastewater have mixed, mg/L
k_d = deoxygenation rate constant, d^{-1}
k_r = reaeration rate constant, d^{-1}
t = time of travel of wastewater discharge downstream, d
D_0 = initial deficit after river and wastewater have mixed, mg/L
When $k_r = k_d$, Equation reduces to:

$$D = (k_d\, t\, L_0 + D_0)\, e^{-k_d t}$$

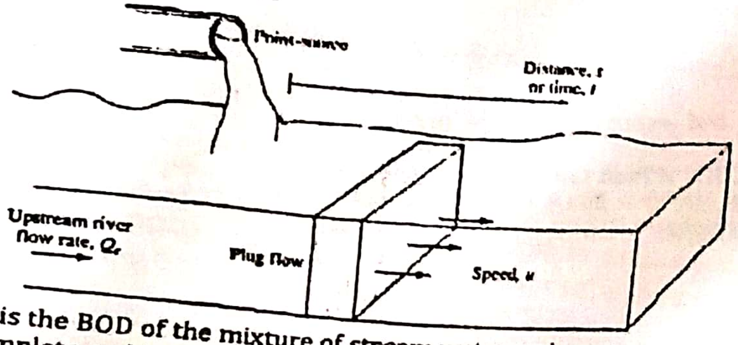
Time at which the deficit is a maximum,

$$t_c = \frac{1}{k_r - k_d} \ln\left\{\frac{k_r}{k_d}\left[1 - \frac{D_0(k_r - k_d)}{k_d L_0}\right]\right\}$$

Reaeration. The value of k_r depends on the degree of turbulent mixing, which is related to stream velocity, and on the amount of water surface exposed to the atmosphere compared to the volume of water in the river. A narrow, deep river will have a much lower kr than a wide, shallow river.

$$k_r = \frac{3.9\, v^{0.5}}{H^{1.5}}$$

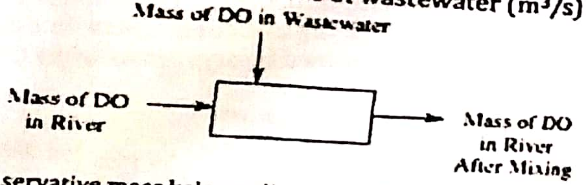
k_r = reaeration rate constant at 20°C, day^{-1}
v = average stream velocity, m/s
H = average stream depth, m



Lo is the BOD of the mixture of stream water and wastewater at the point of discharge. Assuming complete and instantaneous mixing.

$$L_o = \frac{Q_w L_w + Q_r L_r}{Q_w + Q_r}$$

L_o = ultimate BOD of the mixture of streamwater and wastewater (mg/L)
L_r = ultimate BOD of the river just upstream of the point of discharge (mg/L)
L_w = ultimate BOD of the wastewater (mg/L)
Q_r = Volumetric flow rate of the river just upstream of the discharge point (m^3/s)
Q_w = Volumetric flow rate of wastewater (m^3/s)



Conservative mass balance diagram for DO mixing.

Q_w = volumetric flow rate of wastewater, m^3/s
Q_r = volumetric flow rate of the river, m^3/s
DO_w = dissolved oxygen concentration in the wastewater, g/m^3
DO_r = dissolved oxygen concentration in the river, g/m^3

$$DO = \frac{Q_w\,DO_w + Q_r\,DO_r}{Q_w + Q_r}$$

Oxygen Deficit. The DO sag equation has been developed using oxygen deficit rather than dissolved oxygen concentration. The oxygen deficit is the amount by which the actual dissolved oxygen concentration is less than the saturation value with respect to oxygen in the air:

$D = DO_s - DO$
D = Oxygen deficit, mg/L
DO = Actual concentration of dissolved oxygen, mg/L
DO_s = Saturation concentration of dissolved oxygen at the temperature of the river after mixing, mg/L, and The saturation value of dissolved oxygen is heavily dependent on water temperature it decreases as the temperature increases.

Initial Deficit. The beginning of the DO sag curve is at the point where a waste discharge mixes with the river. The initial deficit is calculated as the difference between saturated DO and the concentration of the DO after mixing.

$$D_0 = DO_s - \frac{Q_w DO_w + Q_r DO_r}{Q_w + Q_r}$$

D_0 = Initial deficit after river and waste have mixed, mg/L.

Question: What is BOD and COD? Which one is greater and why?
(BEPZA – 2016, DTCA – 2018, BPDB – 2018, WRGCL – 2014, BWDB – 2014, BSEC – 2014 TGTDCL – 2014, WASA – 2017, BHP – 2017, DESCO – 2019, DSCC – 2019, SGFL – 2020, PGCB – 2020)

Solution:

Biochemical oxygen demand (BOD) is the amount of dissolved oxygen needed by aerobic biological organisms to break down organic material present in a given water sample at certain temperature over a specific time period.

Chemical Oxygen Demand (COD) is the measure of the capacity of water to consume oxygen during the decomposition of organic matter and the oxidation of inorganic chemicals such as ammonia and nitrite.

COD measures all organic compounds that can be chemically oxidized. On the other hand BOD measures the dissolved oxygen consumed by organisms to oxidize organic compounds. In other words, BOD measures only the organic compounds that can be consumed by organisms while COD measures all. Hence, COD should always be higher than BOD.

Question: Why should BOD be determined? (ARMY – 2014)

Solution:

- Determination of the size of waste treatment facilities.
- Measurement of the efficiency of some treatment process.

Question: Why 5 days BOD measure in laboratory? (MPA – 2019)

Solution:

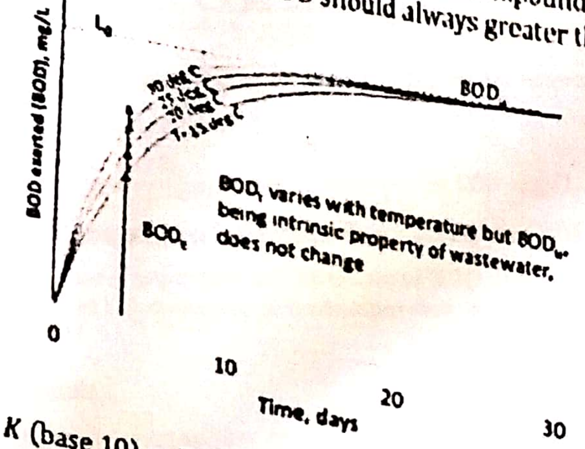
In Laboratory, The BOD value is measured by measuring the difference of dissolved oxygen (DO) of the sample after 5 days of incubation at 20 degrees centigrade. One of the reasons to use incubation period of 5 days for BOD determination is to eliminate oxygen demand for nitrification (Due to low growth rate of nitrifying bacteria, the nitrogenous BOD demand normally occurs from 6 to 10 days), and to find out only carbonaceous oxygen demand.

1. DO (Dissolved Oxygen) is maximum at 5 days
2. 80-95 % decomposition at 5 days
3. Bacterial Process is happen within 5 days

Question: Why COD is greater than BOD? Draw BOD curves for different temperatures. (PGCB – 2018)

Solution:

COD measures all organic compounds that can be chemically oxidized. On the other hand, BOD measures the dissolved oxygen consumed by organisms to oxidize organic compounds. In other words, BOD measures only the organic compounds that can be consumed by organisms while COD measures all. Hence, COD should always greater than BOD.



BOD_t varies with temperature but BOD_u, being intrinsic property of wastewater, does not change

K (base 10) = K (base e)/2.303

Question: A sample of sewage was incubated for 2 days and its BOD was found to be 200 ppm at a temperature of 20°C. Compute its 5 day BOD, the rate constant is 0.1 /day (base 10).

Solution:

$$BOD_2 = BOD_u\,(1 - 10^{-K\,t})$$

$$BOD_u = \frac{BOD_2}{(1 - 10^{-K\,t})} = \frac{200}{(1 - 10^{-0.1\,x\,5})} = 541.90 \text{ ppm}$$

$$BOD_5 = BOD_u\,(1 - 10^{-k\,t}) = 541.90\,(1 - 10^{-0.1\,x\,5}) = 370.53 \text{ ppm}$$

Question: Define BOD. Determine the ultimate BOD for a sewage having 5 day BOD at 20°C is 150 mg/L. Assume, reaction arte constant is 0.22/day (BIFPCL – 2015, BCIC – 2016, JOCL – 2018)

Solution:

$$BOD_5 = BOD_u\,(1 - e^{-k\,t})$$

$$BOD_u = \frac{BOD_5}{(1 - e^{-k\,t})} = \frac{150}{(1 - e^{-5\,x\,0.22})} = 224.84 \text{ mg/L}$$

Question: If the BOD$_5$ is 102.5 mg/L and k = 0.23/day at 20°C temperature. Determine the ultimate BOD. (RPGCL – 2017, BWDB – 2018)

Solution:

$$BOD_5 = BOD_u\,(1 - e^{-k\,t})$$

$$BOD_u = \frac{BOD_5}{(1 - e^{-k\,t})} = \frac{102.5}{(1 - e^{-5\,x\,0.23})} = 150 \text{ mg/L}$$

Question: The amount of BOD$_5$ in a sewage found 200 mg/L at temperature 20°C. If k = 0.22/day, then determine the BOD$_{10}$ at the same temperature.
(MPL – 2017, BPDB – 2018, SGFCL – 2018)

Solution:

$$BOD_5 = BOD_u\,(1 - e^{-k\,t})$$

$$BOD_u = \frac{BOD_5}{(1 - e^{-k\,t})} = \frac{200}{(1 - e^{-0.22\,x\,5})} = 299.79 \text{ mg/L}$$

$$BOD_{10} = BOD_u\,(1 - e^{-k\,t}) = 337.02\,(1 - e^{-0.22\,x\,10}) = 266.57 \text{ mg/L}$$

Question: The amount of BOD$_5$ in a sewage found 200 mg/L at temperature 20°C. If k = 0.22/day, then determine the ultimate BOD. (Combined Bank – 2020)

Solution:

$$BOD_5 = BOD_u\,(1 - e^{-k\,t})$$

$$BOD_u = \frac{BOD_5}{(1 - e^{-k\,t})} = \frac{200}{(1 - e^{-0.22\,x\,5})} = 299.79 \text{ mg/L}$$

Question: The dilution factor P for an unseeded mixture if waste and water is 0.030. The DO of the mixture is initially 9.0 mg/L, and after five days it has dropped to 3.0 mg/L. The reaction constant k has been found to be 0.22 day^{-1}.

a. What is the five day BOD of the waste?
b. What would be the ultimate carbonaceous BOD?
c. What would be the remaining oxygen demand after five days?

Solution:

(*a*) The oxygen consumed in the first five days is

$$BOD_5 = \frac{DO_i - DO_f}{P} = \frac{9-3}{0.03} = 200 \text{ mg/L}$$

(*b*) The total amount of oxygen needed to decompose the carbonaceous portion of the waste is,

$$BOD_5 = BOD_u\,(1 - e^{-k\,t})$$

$$BOD_u = \frac{BOD_5}{(1-e^{-k\,t})} = \frac{200}{(1-e^{-0.22 \times 5})} = 300 \text{ mg/L}$$

(*c*) The remaining oxygen demand after five days is = 300 – 200 = 100 mg/L

Question: If a wastes had an ultimate BOD equal to 300 mg/L. At 20° c, the five day BOD was 200 mg/L and the reaction rate constant was 0.22/day. What would the five day BOD of this waste be at 25° C?

Solution:

Adjust the reaction rate constant with using a value of θ equal to 1.047

$$K_{25} = K_{20}\,\theta^{(T-20)} = 0.22 \times 1.047^{(25-20)} = 0.277/\text{day}$$

$$BOD_5 = BOD_u\,(1 - e^{-k\,t}) = 300\,(1 - e^{-0.277 \times 5}) = 225 \text{ mg/L}$$

Question: If the BOD$_5$ at 20°C of a sewage sample is 320 mg/L. Calculate its 10 days BOD at 30°C if k = 0.23/day. (DSCC – 2016)

Solution:

$$BOD_5 = BOD_u\,(1 - e^{-k\,t})$$

$$BOD_u = \frac{BOD_5}{(1-e^{-k\,t})} = \frac{320}{(1-e^{-0.23 \times 5})} = 468.27 \text{ mg/L}$$

$$K_{30} = K_{20}\,\theta^{(T-20)} = 0.23 \times 1.047^{(30-20)} = 0.36/\text{day}$$

$$BOD_{10} = BOD_u\,(1 - e^{-k\,t}) = 468.27\,(1 - e^{-0.36 \times 10}) = 455.47 \text{ mg/L}$$

Question: Waste water এ BOD_5 ২০ ডিগ্রি সেলসিয়াস তাপমাত্রায় পাওয়া যায় 150 mg/L ,K এর মান 0.23 / day হলে ১৫ ডিগ্রি সেলসিয়াস তাপমাত্রায় $BOD_৪$ এর মান কত হবে ?(HED – 2020)

Solution:

$$BOD_5 = BOD_u\,(1 - e^{-k\,t})$$

$$BOD_u = \frac{BOD_5}{(1 - e^{-kt})} = \frac{150}{(1 - e^{-0.23 \times 5})} = 219.50 \text{ mg/L}$$

$$K_{15} = K_{20}\,\theta^{(T-20)} = 0.23 \times 1.047^{(15-20)} = 0.182/\text{day}$$

$$BOD_8 = BOD_u\,(1 - e^{-kt}) = 219.50\,(1 - e^{-0.182 \times 8}) = 168.31 \text{ mg/L}$$

Question: For a domestic sewage having 5 day BOD of 200 mg/l at 20° C. Calculate the BOD at 1 and 5 days at 12°C. Assume the value of R as 0.18 per day at 20°C. (38th BCS)

Solution:

$$BOD_5 = BOD_u\,(1 - e^{-kt})$$

$$BOD_u = \frac{BOD_5}{(1 - e^{-Rt})} = \frac{200}{(1 - e^{-0.18 \times 5})} = 337.02 \text{ mg/L}$$

$$R_{15} = R_{20}\,\theta^{(T-20)} = 0.18 \times 1.047^{(12-20)} = 0.124/\text{day}$$

$$BOD_1 = BOD_u\,(1 - e^{-Rt}) = 337.02\,(1 - e^{-0.124 \times 1}) = 39.30 \text{ mg/L}$$

$$BOD_5 = BOD_u\,(1 - e^{-Rt}) = 337.02\,(1 - e^{-0.124 \times 5}) = 155.72 \text{ mg/L}$$

Question: If a 2% solution of sewage is incubated for 5 days at 20°C and dissolved oxygen depletion was 5 ppm, determine BOD5. (PGCB – 2017)

Solution:

Here, $P = 2\% = 0.02$

$$BOD_5 = \frac{DO_i - DO_f}{P} = \frac{5}{0.02} = 250 \text{ mg/L}$$

Question: A test bottle containing just seeded dilution water has its DO level drop by 1.0 mg/L in five days test. A 300 mL BOD bottle filled with 15 mL of waste water and the rest seeded dilution water (sometimes expressed as a dilution of 1:20) experiences a drop of 7.2 mg/L in the same time period. What would be the five day BOD of the waste?

Solution:

The dilution factor, $P = 15/300 = 0.05$

$$BOD_5 = \frac{7.2 - 1\,(1 - 0.05)}{0.05} = 125 \text{ mg/L}$$

Question: A standard five day BOD test is run using a mix consisting of four parts distilled water and one part wastewater (no seed). The initial DO of the mix is 9 mg/L and the DO after five days is determined to be 1 mg/L. What is BOD5?

Solution:

The dilution factor, $P = 1/5 = 0.2$

$$BOD_5 = \frac{DO_i - DO_f}{P} = \frac{9 - 1}{0.2} = 250 \text{ mg/L}$$

Question: A mixture consisting of 30 mL of waste and 270 mL of seeded dilution water has an initial DO of 8.55 mg/L; after five days, it has a final DO of 2.40 mg/L. Another bottle containing just seeded dilution water has an initial DO of 8.75 mg/L and a final DO of 8.53 mg/L. Find the 5-day BOD of the waste.

Solution:

The dilution factor, $P = 30/300 = 0.1$

$$BOD_5 = \frac{(DO_i - DO_f) - (B_i - B_f)(1 - P)}{P}$$

$$BOD_5 = \frac{(8.55 - 2.40) - (8.75 - 8.53)(1 - 0.1)}{0.1} = 59.5 \text{ mg/L}$$

Question: Some wastewater has a BOD₅ of 150 mg/L at 20°C. The reaction rate k at that temperature has been determined to be 0.23/day.

(a) Find the ultimate carbonaceous BOD.
(b) Find the reaction rate coefficient at 15°C.
(c) Find BOD₅ at 15°C.

Solution:

$$BOD_5 = BOD_u\,(1 - e^{-kt})$$

$$BOD_u = \frac{BOD_5}{(1 - e^{-kt})} = \frac{150}{(1 - e^{-0.23 \times 5})} = 219.5 \text{ mg/L}$$

$$K_{15} = K_{20}\,\theta^{(T-20)} = 0.23 \times 1.047^{(15-20)} = 0.183/\text{day}$$

$$BOD_5 = BOD_u\,(1 - e^{-kt}) = 219.5\,(1 - e^{-0.18 \times 5}) = 131.5 \text{ mg/L}$$

Question: Waste water 40 ml is mixed with diluted water 360 ml in a bottle. DO_i = 8.5 mg/L, DO_f = 3.5 mg/L, then BOD₅? (WARPO – 2015)

Solution:

$$DF = \frac{\text{Bottle volume}}{\text{Sample volume}} = \frac{360 + 40}{40} = 10$$

$$BOD_5 = (DO_i - DO_f) \times DF = (8.5 - 3.5) \times 10 = 50 \text{ mg/L}$$

Question: Determine the 5 day BOD for a 15 ml sample that is diluted with dilution water to a total volume of 300 ml when the initial DO concentration is 8 mg/l and after 5 days, has been reduced to 2 mg/l.

Solution:

$D_O = 8$ mg/L

$D_5 = 2$ mg/L

$$P = \frac{15}{300} = 0.05$$

$$BOD_5 = \frac{D_O - D_5}{P} = \frac{8 - 2}{0.05} = 120 \text{ mg/L}$$

Question: A sample having 25 ml sewage water to dilute in 300 ml. $D_i = 8.7, D_f = 3.7$ and the dilute water seed sample $D_i = 3.7, D_f = 2.6$. Determine BOD$_5$. (WASA – 2014, BCIC – 2017)

Solution:

$$\text{Here, } P = \frac{25}{300} = 0.08333$$

$$BOD_5 = \frac{(DO_i - DO_f) - (B_i - B_f)(1 - P)}{P}$$

$$= \frac{(8.7 - 3.7) - (3.7 - 2.6)(1 - 0.08333)}{0.08333} = 47.90 \text{ mg/L}$$

Question: The dilution factor is 50 for a 5 days BOD test having initial dissolve oxygen 7.4 mg/L and final dissolve oxygen of 4.3 mg/L. The rate of constant (e base) is 0.2/day. Determine the ultimate BOD of the sample. (BCIC – 2019, BADC – 2020)

Solution:

$BOD_5 = (DO_i - DO_f) \times DF = (7.4 - 4.3) \times 50 = 155 \text{ mg/L}$

Now, $BOD_5 = BOD_u\,(1 - e^{-kt})$

$155 = BOD_u\,(1 - e^{-0.2 \times 5})$

$BOD_u = 245.20 \text{ mg/L}$

Question: Dilution factor, initial and final dissolved oxygen given 0.6, 3.6 and 2.6. Determine BOD$_5$, BOD remaining and ultimate BOD. $K = 0.22 \text{ day}^{-1}$ (DESCO – 2015)

Solution:

(*i*) $BOD_5 = (BOD_i - BOD_f) \times DF = (3.6 - 2.6) \times 0.6 = 0.6 \text{ mg/L}$

(*ii*) $BOD_5 = BOD_u(1 - e^{-kt})$

$0.66 = BOD_u\,(1 - e^{-0.22 \times 5})$

$BOD_u = 0.9 \text{ mg/L}$

(*iii*) Remaining BOD, $BOD_t = BOD_u\; e^{-kt} = 0.9 \times e^{-0.22 \times 5} = 0.29 \text{ mg/L}$

Question: The dilution factor = 0.5, value of DO initial 7.4 after 5 days 4.4 and BOD reaction rate constant 0.2 per day. Find out (*i*) BOD$_5$ (*ii*) ultimate BOD (*iii*) BOD remaining after 3 days. (GTCL – 2016)

Solution:

(*i*) $BOD_5 = \dfrac{D_i - D_f}{p} = \dfrac{7.4 - 4.4}{0.5} = 6 \text{ mg/L}$

(*iii*) $BOD_5 = BOD_u(1 - e^{-kt})$

$6 = BOD_u\,(1 - e^{-0.2 \times 5})$

$BOD_u = 9.49 \text{ mg/L}$

(*iii*) $BOD_3 = BOD_u(1 - e^{-kt}) = 9.49 \times (1 - e^{-0.2 \times 3}) = 4.28 \text{ mg/L}$

Question: Ten 5 ml samples of waste water one placed in 300 ml BOD bottles and diluted to full volume. Half of the bottles are tasted immediately and the average initial concentration of dissolved oxygen = 7.9 mg/L the remaining bottles are incubated for 5 days after which the average dissolved oxygen is determined to be 4.5 mg/L. (K_1 = 0.13 day-1) Find out- i) Standard BOD ii) Ultimate carbonaceous BOD. (BB AD – 2018)

Solution:

Total sample = 10 x 5 = 50 ml.

$$P = \frac{50}{300} = 0.1667$$

$$BOD_5 = \frac{D_0 - D_5}{P} = \frac{7.9 - 4.5}{0.1667} = 20.39 \text{ mg/L.}$$

Now, $BOD_5 = BOD_u(1 - 10^{-k_1 t})$

$20.39 = BOD_u\,(1 - 10^{-0.13 \times 5})$

Ultimate carbonaceous BOD, BOD_u = 26.27 mg/L

Question: The dissolved oxygen in an unseeded sample of diluted waste having an initial DO of 8 mg/L and final dissolve oxygen after 5 days is 4 mg/L. If the sample is diluted in 1:50, find the BOD_5 of the sample. If this BOD_5 water discharge in an open source at a rate of 10 ft³/sec what will be BOD load per year (ton/year)? (NHA – 2019)

Solution:

$$P = \frac{1}{50}$$

we know, $BOD_5 = \dfrac{DO_i - DO_f}{P} = (8 - 4) \times 50 = 200 \text{ mg/L} = 0.2 \text{ kg/m}^3$

Discharge = 10 ft³/sec = $\dfrac{10 \times 3600 \times 24}{3.28 \times 3.28 \times 3.28} = 24484.55 \text{ m}^3\text{/day}$

BOD Load per year = 24484.55 x 0.2 x 365 = 1787372.49 kg/year = 1787.37 ton/year

Question: A municipal waste water treatment plant discharge 1.2 m³/sec of effluent having BOD of 60 mg/L that has a flow of 9.3 m³/sec and BOD 6 mg/L. Assume complete and mixing estimate the BOD of the river just drawdown of the rainfall. (BPDB – 2015, ERL – 2017)

Solution:

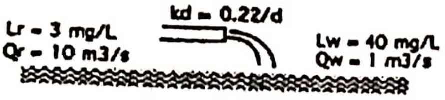
Here, $BOD_w \times Q_w + BOD_R \times Q_R = BOD_m \times (Q_w + Q_R)$

$60 \times 1.2 + 6 \times 9.3 = BOD_m \times (1.2 + 9.3)$

$BOD_m = 12.17$ mg/L

Question: A wastewater treatment plant discharges 1 m^3/s of effluent having an ultimate BOD of 40 mg/L into a stream flowing at 10 m^3/s. Just upstream from the discharge point, the stream has an ultimate BOD of 3 mg/L. The deoxygenation constant k_d is estimated at 0.22/day. (a) Assuming complete and instantaneous mixing find the ultimate BOD of the mixture of waste and river just downstream from the outfall. (b) Assuming a constant cross sectional area for the stream equal to 55 m^2, what ultimate BOD would you expect to find at a point 10,000 m downstream?

Solution:



$$L_0 = \frac{Q_w L_w + Q_r L_r}{Q_w + Q_r} = \frac{1 \times 40 + 10 \times 3}{10 + 1} = 6.4 \text{ mg/L}$$

At 10,000 m downstream:

$$t = \frac{\text{distance}}{\text{speed}} = \frac{10,000}{1/55} = 550000 \text{ s} = 0.578 \text{ days}$$

$$BOD_t = BOD_u\ e^{-kt} = 6.4 \times e^{-0.22 \times 0.578} = 5.6 \text{ mg/L}$$

Question: The town of State College discharges 17,360 m^3/d of treated wastewater into the Bald Eagle Creek. The treated wastewater has a BOD_5 of 12 mg/L and a k of 0.12 d^{-1} at 20°C. Bald Eagle Creek has a flow rate of 0.43 m^3/s and an ultimate BOD of 5.0 mg/L. The DO of the river is 6.5 mg/L and the DO of the wastewater is 1.0 mg/L. Compute the DO and initial ultimate BOD after mixing.

Solution:

$$Q_w = 17360 \text{ m}^3/\text{d} = 0.20 \text{ m}^3/\text{s}$$

$$DO \text{ after mixing, } DO = \frac{Q_w DO_w + Q_r DO_r}{Q_w + Q_r} = \frac{0.2 \times 1 + 0.43 \times 6.5}{0.2 + 0.43} = 4.75 \text{ mg/L}$$

$$\text{Ultimate BOD of wastewater, } BOD_u = \frac{BOD_5}{(1 - e^{-kt})} = \frac{12}{(1 - e^{-0.12 \times 5})} = 26.6 \text{ mg/L}$$

Now setting $L_w = L_0$, initial ultimate BOD after mixing,

$$L_0 = \frac{Q_w L_w + Q_r L_r}{Q_w + Q_r} = \frac{0.2 \times 26.6 + 0.43 \times 5}{0.2 + 0.43} = 11.86 \text{ mg/L}$$

Question: The Waramurngundi tannery with a wastewater flow of 0.011 m^3/s and a BOD_5 of 590 mg/L discharges into Djanggawul Creek. The creek has a 10-year, 7-day low flow of 1.7 m^3/s. Upstream of the Waramurungundi tannery, the BOD_5 of the creek is 0.6 mg/L. The BOD rate constants (k) are 0.115 day^{-1} for the Waramurungundi tannery and 3.7 day^{-1} for the creek. Calculate the initial ultimate BOD after mixing. (BWDB – 2020)

Solution:

Given: Tannery $Q_w = 0.011 \text{ m}^3/\text{s}$, $BOD_5 = 590$ mg/L, Creek $Q_r = 1.7 \text{ m}^3/\text{s}$

BOD_5 upstream of tannery = 0.6 mg/L, $k_{tannery} = 0.115 \text{ day}^{-1}$, $k_{creek} = 3.7 \text{ day}^{-1}$.

Calculate the ultimate BOD of tannery wastewater

$$BOD_u = \frac{BOD_5}{(1 - e^{-kt})} = \frac{590}{(1 - e^{-0.115 \times 5})} = 1349.2 \text{ mg/L}$$

$L_w = 1349.2$ mg/L

Calculate the ultimate BOD of Djanggawul Creek

$$BOD_u = \frac{BOD_5}{(1 - e^{-kt})} = \frac{0.6}{(1 - e^{-3.7 \times 5})} = 0.6 \text{ mg/L}$$

$L_r = 0.6$ mg/L

Calculate the initial ultimate BOD by simple mass balance

$$L_0 = \frac{Q_w L_w + Q_r L_r}{Q_w + Q_r} = \frac{0.011 \times 1349.2 + 1.7 \times 0.6}{0.011 + 1.7} = 9.269 \text{ mg/L}$$

Question: Just below the point where a continuous discharge of pollution mixes with river, the BOD is 10.9 mg/L and DO is 7.6 mg/L. The river and waste mixture has a temperature of 20°C, a deoxygenation constant of 0.20/day, an average flow speed 0.3 m/s, and an average depth of 3.0 m. The saturation value of DO at 20°C is 9.1 mg/L and reaeration constant is 0.41/day.

a. Find the time and distance downstream at which the oxygen deficit is at a maximum.
b. Find the minimum value of DO. (DMTCL – 2019)

Solution:

Initial deficit, $D_0 = 9.1 - 7.6 = 1.5\ mg/L$

Time at which the deficit is a maximum,

$$t_c = \frac{1}{k_r - k_d} \ln\left\{\frac{k_r}{k_d}\left[1 - \frac{D_0(k_r - k_d)}{k_d\, L_0}\right]\right\}$$

$$t_c = \frac{1}{0.41 - 0.20} \ln\left\{\frac{0.41}{0.20}\left[1 - \frac{1.5\ (0.41 - 0.20)}{0.20 \times 10.9}\right]\right\} = 2.67 \text{ days}$$

So the critical distance downstream would be,

$$x_c = u\, t_c = 0.30 \times 2.67 \times 24 \times 3600 = 69300 \text{ m} = 69.3 \text{ km}$$

The maximum deficit,

$$\text{Oxygen deficit, } D = \frac{k_d\, L_0}{k_r - k_d}\,(e^{-k_d t} - e^{-k_r t}) + D_0\, e^{-k_r t}$$

$$D = \frac{0.20 \times 10.9}{0.41 - 0.20}\,(e^{-0.20 \times 2.67} - e^{-0.41 \times 2.67}) + 1.5\, e^{-0.41 \times 2.67} = 3.1 \text{ mg/L}$$

The minimum value of DO will be the saturation value minus maximum deficit:

$$DO_{min} = 9.1 - 3.1 = 6.0 \text{ mg/L}$$

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Question: A canal exerts wastewater in a river at 8000 m^3/day. BOD of the waste water is given in 18 mg/L. what is the total amount of BOD exerted in the river (DMTCL – 2019)

Solution:

$$\text{Total amount of BOD} = \frac{8000 \times 18 \times 1000}{1000 \times 1000} = 144 \text{ kg/day}$$

Question: A canal exerts wastewater in a river at 55000 m^3/day. BOD of the waste water is given in 110 mg/L. what is the total amount of BOD exerted in the river? If a treatment plant is treating the waste water to remove 70% BOD, what is the amount of BOD exerted now? (GTCL – 2016)

Solution:

$$\text{Total amount of BOD} = \frac{55000 \times 110 \times 1000}{1000 \times 1000} = 6050 \text{ kg/day}$$

$$\text{Amount of BOD exerted} = 6050 - \frac{6050 \times 70}{100} = 1815 \text{ kg/day}$$

Question: The BOD of a waste water sample is estimated to be 180 mg/L. What volume of undiluted sample should be added to a 300 mL bottle? Also, what are the sample size and dilution factor using this volume? Assume that 4 mg/L BOD can be consumed in the BOD bottle. (PGCB – 2019)

Solution:

$$\text{Estimate the sample size needed: Sample size} = \frac{4}{180} \times 100 = 2.22\%$$

Estimate the volume of undiluted sample needed since the volume of diluted sample is 300 mL:

Vol. of undiluted sample = 0.0222 x 300 mL = 6.66 mL

Therefore a convenient sample volume would be 7.00 mL

Compute the actual sample size and dilution factor:

$$\text{Sample size} = \frac{7}{300} \times 100 = 2.33\%$$

$$\text{Dilution factor} = \frac{300}{7} = 42.9$$

Question: Let there is a community with a population of 35,000. The solid waste generation rate is 6.5 lb/capita-day. There is a necessity to design a landfill for the community. Estimate the required landfill area. Consider that, the compacted specific weight of solid wastes in landfill 800 lb/yd^3 and average depth of compacted solid waste is 20 ft. (JB – 2017)

Solution:

Daily Solid waste generation rate = 35000 x 6.5 = 227500 lb/day

$$\text{Volume required} = \frac{227500}{800} = 284.375 \text{ yd}^3\text{/day}$$

$$\text{Area required} = \frac{284.375}{20 \times 0.33} = 42.69 \text{ yd}^2\text{/day}$$

$$\text{Area required} = 42.69 \times 365 = 15585 \text{ yd}^2\text{/year}$$

Trickling filters: Trickling filters (TFs) are used to remove organic matter from wastewater. The TF is an aerobic treatment system that utilizes microorganisms attached to a medium to remove organic matter from wastewater. This type of system is common to a number of technologies such as rotating biological contactors and packed bed reactors

Water Recirculation: An important consideration in the operation of a trickling filter is that the microorganisms (the zoogleal slime) does not move. They just hang onto the media as slime waiting for the food to trickle by. To give the microorganisms another opportunity to eat food they missed, operators recycle clarified effluent. This is called recirculation.

Recirculation is used to reduce the organic loading, improve sloughing, reduce odors and reduce or eliminate filter fly or ponding problems. The amount of recirculation is dependent on the design of the treatment plant and the operational requirements of the process. Recirculation flow may be expressed as a specific flow rate.

Types of Filters: Trickling filters are classified as high rate or low rate, based on the organic and hydraulic loading applied to the unit.

A well operated low rate trickling filter in combination with secondary settling tank may remove 75 to 90% BOD and produce highly nitrified effluent. It is suitable for treatment of low to medium strength domestic wastewaters.

The high rate trickling filter, single stage or two stage are recommended for medium to relatively high strength domestic and industrial wastewater. The BOD removal efficiency is around 75 to 90% but the effluent is only partially nitrified.

Single stage unit consists of a primary settling tank, filter, secondary settling tank and facilities for recirculation of the effluent. Two stage filters consist of two filters in series with a primary settling tank, an intermediate settling tank which may be omitted in certain cases and a final settling tank.

$$\text{Recirculation factor, } F = \frac{1+R}{(1+0.1\,R)^2}$$

$$\text{Efficiency for single stage, } E_1 = \frac{100}{1+0.532\sqrt{\frac{W}{VF}}} = \frac{100}{1+0.532\sqrt{\frac{Q\ C}{V\ F}}}$$

E_1 = Efficiency of BOD removal for first stage at 20°C

W = BOD loading to filter, kg/day

V = Volume of filter media, m^3

F = Recirculation factor

Q = wastewater flow rate, m^3/d

C = influent BOD, kg/m^3

For the second stage filter, the formula becomes

$$E_1 = \frac{100}{1 + \frac{0.0561}{1 - E_1}\sqrt{\frac{W'}{VF}}}$$

W' = BOD loading applied to second stage filter, kg/day

Adjustments to the efficiency based on wastewater temperature are given by:

$E_T = E\,(1.035)^{T-20}$

E_T = Efficiency of BOD removal at temperature T in percent

E = efficiency of BOD removal at 20°C given by the equations in percent

T = wastewater temperature in °C

Question: Calculate BOD removal efficiency for the single stage high rate trickling filter. BOD loading is 750 g/m³/d and re-circulation ratio is 0.60. (30th BCS)

Solution:

BOD loading = 750 g/m³/d = 0.75 kg/m³/d

$$\text{Recirculation factor, } F = \frac{1 + R}{(1 + 0.1\,R)^2} = \frac{1 + 0.6}{(1 + 0.1 \times 0.6)^2} = 1.5094$$

$$\text{Efficiency for single stage, } E_1 = \frac{100}{1 + 0.532\sqrt{\frac{W}{VF}}} = \frac{100}{1 + 0.532\sqrt{\frac{W}{V} \times \frac{1}{F}}}$$

$$E_1 = \frac{100}{1 + 0.532\sqrt{0.75 \times \frac{1}{1.5094}}} = 72.72\ \%$$

Question: Using the NRC equations, determine the BOD₅ of the effluent from a single stage low rate trickling filter that has a filter volume of 1443 m³, a hydraulic flow rate of 1900 m³/d and a recirculation factor of 2.78. The influent BOD₅ is 150 mg/L.

Solution:

Wastewater flow rate, Q = 1900 m³/d

Influent BOD, C = 150 mg/L = 0.15 kg/m³

$$\text{Efficiency for single stage, } E_1 = \frac{100}{1 + 0.532\sqrt{\frac{Q\,C}{V\,F}}}$$

$$E_1 = \frac{100}{1 + 0.532\sqrt{\frac{1900 \times 0.15}{1443 \times 2.78}}} = 87.58\ \%$$

The concentration of BOD₅ in the effluent is,

$C_e = (1 - 0.8758) \times 150 = 18.63$ mg/L

Question: A lagoon having three cells, each 115,000 m^2 in area, a minimum operating depth of 0.6 m and a maximum operating depth of 1.5 m, receives 1,900 m^3/d of wastewater having an average BOD_5 of 122 mg/L. What is the BOD_5 loading and what is the detention time?

Solution:

$$BOD_5 \text{ mass} = \frac{122 \text{ x } 1900 \text{ x } 1000}{10^6} = 231.8 \text{ kg/d}$$

$$\text{Area} = \frac{115000}{10000} = 11.5 \text{ ha. each}$$

$$BOD_5 \text{ loading} = \frac{231.8}{11.5} = 20.2 \text{ kg/ha. d}$$

$$\text{Detention time} = \frac{115000 \text{ x } 3 \text{ x } (1.5 - 0.6)}{1900} = 163.4 \text{ days}$$

Question: Waste water flowing from a city at a rate of 1.5 MGD is treated by primary sedimentation and secondary trickling filters with total surface area 700000 ft^2. The influent BOD_5 concentration is 300 mg/l and suspended solids concentration is 220 mg/l. The primary treatment process removes 33 % of the BOD_5. Calculate the required loading rate in $kg/ft^2/d$. (DPDC – 2020)

Solution:

Total BOD applied to filters $= (1 - 0.33) \text{ x } 1.5 \text{ x } 10^6 \text{x } 3.78 \text{ x } 300 \text{ x } 10^{-6} = 1139.67$ kg/day

Suspended solid $= 1.5 \text{ x } 10^6 \text{ x } 3.78 \text{ x } 220 \text{ x } 10^{-6} = 1247.40$ kg/day

Total solid production $= 1139.67 + 1247.4 = 2387.07$ kg/day

$$\text{Loading rate} = \frac{2387.07}{700000} = 3.410 \text{ x } 10^{-3} \text{ kg/ft}^2\text{/day}$$

Question: A trickling filter plant treats 1500 cum per day of sewage with a BOD_5 of 220 mg/L and a suspended solid concentration of 250 mg/L. Estimate the total solid production assuming that primary clarification removes 30% of BOD and 60% of influent Solids. Take the solid production in the trickling filter as 0.5 kg/kg of the applied BOD.

Solution:

Solids removed in primary clarification units of the trickling filter plant,

$$= 60\% \text{ of influent suspended solids} = \frac{60}{100} \text{ x } 250 = 150 \text{ mg/L} = 0.15 \text{ kg/m}^3$$

Solids removed per day $= 0.15 \text{ x } 1500 = 225$ kg

BOD_5 removed in primary clarification $= 30\%$

BOD applied to filters $= 100 - 300 = 70\%$

Total BOD applied to filters $= 0.7 \text{ x } 220 \text{ x } 10^3 \text{ x } 10^{-6} \text{ x } 1500 = 231$ kg/day

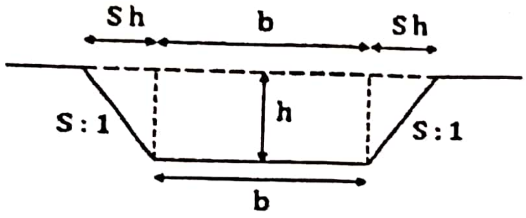
Solid production in filters $= 0.5$ kg/kg of BOD applied $= 0.5 \text{ x } 231 = 115.5$ kg/day

Total solid production = Solid removed in primary clarification + Solids produced in filters

Total solid production $= 225 + 115.5 = 340.5$ kg/day

Question: An aerated lagoon (50 m x 50 m at water surface) is 3 m deep with banks sloped at 2H:1V receives a wastewater flow Of 2.5 MLD with 600 mg/L BOD. Calculate the detention time, volumetric organic loading rate and F/M ratio. (Assuming that equivalent volatile SS concentration in the lagoon is 4000 mg/L = 0.4 kg/m³) (40th BCS)

Solution:



Assume, bottom width of the lagoon = b

Here, $b + 2\,s\,h = 50$

$b = 38$ m

$$\text{Volume of the lagoon, V} = \frac{50 \times 50 + 4 \times \left(\frac{50+38}{2}\right) \times \left(\frac{50+38}{2}\right) + 38 \times 38}{6} \times 3 = 5844 \text{ m}^3$$

Wastewater flow, Q = 2.5 MLD = 2.5×10^6 L/day = 2.5×10^3 m³/day

BOD = 600 mg/L = 6×10^{-4} kg/L

$$\text{Detention time}, t = \frac{\text{Volume}, V}{\text{Flow}, Q} = \frac{5844}{2.5 \times 10^3} = 2.3376 \text{ day}$$

Volumetric organic loading rate = Flow x BOD = 2.5×10^6 L/day x 6×10^{-4} kg/L

= 1500 kg/day

Mixed liquid volatile suspended solids, $MLVSS$ = 0.4 x 5844 = 2337.6 kg

$$F/M \text{ ratio} = \frac{\text{BOD loading rate}}{MLVSS} = \frac{1500}{2337.6} = 0.64 \text{ kg BOD/day per kg MLVSS}$$

Sulfur Oxides

Sulfur oxides may be both primary and secondary pollutants. Power plants, industry, volcanoes, and the oceans emit SO_2, SO_3, and SO_4^{2-} directly as primary pollutants. In addition, biological decay processes and some industrial sources emit H_2S, which is oxidized to form the secondary pollutant SO_2.

The most important oxidizing reaction for H2S appears to be one involving ozone:

$H_2S + O_3 = H_2S + SO_2$

The combustion of fossil fuels containing sulfur yields sulfur dioxide in direct proportion to the sulfur content of the fuel:

$S + O_2 = SO_2$

Question: A coal power uses 10 ton coal which contains 4% of sulfur. Determine the amount of sulfur dioxide emission. (DESCO - 2019)

Solution:

Amount of S = 10 × 0.04 = 0.4 ton = 400 kg

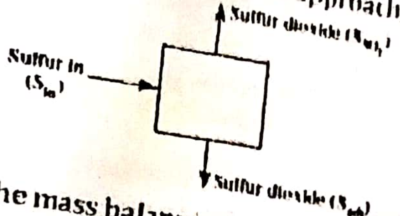
$S + O_2 = SO_2$

0.32 kg sulfur emission = 0.064 kg SO_2

$$400 \text{ sulfur emission} = \frac{0.064}{0.032} \times 400 = 800 \text{ kg}$$

Question: The boropukuria coal is burned at a rate 1.00 kg per second. Analysis of the BUET lab shows the coal revels a sulfur content of 3.00%. What is the annual rate of emission of SO_2? Assume that 5% of the sulfur in the coal ends up in the ash. (PGCB - 2019)

Using the mass balance approach, we begin by drawing a mass balance



The mass balance equation may be written as

$S_{in} = S_{ash} + S_{SO_2}$

The mass of "sulfur in" is

$S_{in} = 1 \text{ kg/s} \times 0.03 = 0.03 \text{ kg/s}$

In one year,

$S_{in} = 0.03 \text{ kg/s} \times 86400 \text{ s/d} \times 365 \text{ d/y} = 9.46 \times 10^5 \text{ kg/y}$

The sulfur in the ash is 5 percent of the input sulfur:

$S_{ash} = 0.05 \times 9.46 \times 10^5 = 4.73 \times 10^4 \text{ kg/y}$

The amount of sulfur available for conversion to SO_2:

$S_{SO_2} = S_{in} - S_{ash} = 9.46 \times 10^5 - 4.73 \times 10^4 = 8.99 \times 10^5 \text{ kg/y}$

The amount of sulfur dioxide formed is determined from the proportional weights of the oxidation reaction

$S + O_2 = SO_2$

GMW = 32 + 32 = 64

The amount of sulfur dioxide formed is then 64/32 of the sulfur available for conversion:

$$S_{SO_2} = \frac{64}{32} \times 8.99 \times 10^5 = 1.80 \times 10^6 \text{ kg/y}$$

WATER SOFTENING

The removal or reduction of hardness from the water is known as water softening. Water is said to be 'hard' when it contains relatively large amounts of bicarbonates, carbonates, sulphates and chlorides of calcium and magnesium dissolved in it. It requires more consumption of soap in producing lather for washing clothes with hard water than soft water. The main advantage of water softening is reduction in the consumption of soap.

Total hardness (mg/L as $CaCO_3$ or meq/L) = Calcium hardness + Magnesium hardness

TH (mg/L as $CaCO_3$ or meq/L) $= Ca^{2+} + Mg^{2+}$

Necessity

- Hard water caused following problems, hence it is essential to remove from water.
- It causes more consumption of soap during washing of clothes.
- It causes serious difficulties in manufacturing processes. Such as paper making, canning, ice making etc.
- It causes formation of scales on the boilers and other hot water heating system.
- It causes choking and clogging problems of house plumbing.

Types of Hardness

- Permanent hardness / Non-carbonate hardness
- Temporary hardness / Carbonate hardness

Permanent hardness is due to the presence of sulphates, chlorides and nitrates of calcium and magnesium and is also known as 'non-carbonate hardness' (NCH). Permanent hardness can't be removed by simple boiling but requires special treatment of softening.

Temporary hardness is due to the presence of carbonates and bicarbonates of calcium and magnesium & is also known as 'carbonate hardness' (CH). It can be removed by boiling or by adding lime.

Total Hardness $(TH) = CH + NCH$

Carbonate Hardness	**Non-carbonate hardness**
Calcium carbonate ($CaCO_3$)	Calcium sulfate ($CaSO_4$)
Magnesium carbonate ($MgCO_3$)	Magnesium sulfate ($MgSO_4$)
Calcium bicarbonate ($Ca(HCO_3)_2$)	Calcium chloride ($CaCl_2$)
Magnesium bicarbonate ($Mg(HCO_3)_2$)	Calcium chloride ($MgCl_2$)
Calcium hydroxide ($Ca(OH)_2$)	
Magnesium hydroxide ($Mg(OH)_2$)	

$$\text{mg/L or ppm as } CaCO_3 = \frac{\text{ion concentration in mg/L x Eq. wt. of } CaCO_3}{\text{Equivalent weight of ion}}$$

Where, ion = Mg, Ca, Fe, Mn, Sr (Strontium)
Eq. wt. of Mg = 12.2, Eq. wt. of Ca = 20, Eq. wt. of Sr = 43.8, Eq. wt. of $CaCO_3$ = 50

Concentration in meq/l can be calculated by the equation:

$$\text{meq/l} = \frac{\text{mg/l}}{\text{Equivalent weight}}$$

Equivalent weight was defined as

$$EW = \frac{\text{Atomic or molecular weight}}{n}$$

The units of EW are grams/equivalent (g/eq) or milligrams/milli equivalent (mg/meq). For calcium, n is equal to the valence or oxidation state in water, so $n = 2$. From the table on the inside cover of the book, the atomic weight of Ca^{2+} is 40.08. The equivalent weight is then

$$EW = \frac{40.08}{2} = 20.04 \text{ mg/meq}$$

Effects of Hardness:

- Wasteful consumption of soap while washing and bathing.
- Modifies color if used in dyeing work and washing clothes.
- Causes corrosion and incrustation of pipelines and fittings.
- Causes corrosion, decreases efficiency and danger of burst of pipe line and boiler.
- Makes food tasteless, more fuel consumption and causes bad effects to our digestive system.

Measurement of Hardness in Water:

Hardness of water is measured in ppm or mg/l of calcium carbonate present in water.

Hardness classification	mg/L as $CaCO_3$	
	U.S.	International
Soft	0–60	0–50
Moderate soft		51–100
Slightly hard		101–150
Moderate hard	61–120	151–200
Hard	121–180	201–300
Very hard	>180	>300

Alkalinity

Alkalinity is a measure of water's ability to neutralize acids. Alkalinity and total hardness are usually nearly equal in concentration (when they are both reported in mg/L as $CaCO_3$ because they form from the same minerals. If alkalinity is much greater than total hardness, it may indicate that your water has passed through a water softener. If alkalinity is much less than total hardness it may signify elevated levels of chloride, nitrate or sulfate. Water with low levels of alkalinity (less than 150 mg/L) is more likely to be corrosive.

Types of Alkalinity

Alkalinity is a measure of the acid-neutralizing capacity of water. It is an aggregate of the sum of all titratable bases in the sample. When pH of water is > 7, it is said to be alkaline. Alkalinity in most natural waters is due to the presence of carbonate (CO_3^{--}), bicarbonate (HCO_3^{--}), and hydroxyl (OH^-) anions. Alkalinity is mainly two types, alkalinity due to bicarbonate and alkalinity due to bicarbonate.

Alkalinity = $[HCO_3^-] + 2\,[CO_3^{2-}] + [OH^-] - [H^+]$
Where [ ] refers to concentrations in moles/L.

Alkalinity = $[HCO_3^-] + [CO_3^{2-}] + [OH^-] - [H^+]$
Where [ ] refers to concentrations in meq/L or mg/L as $CaCO_3$.

Alkalinity caused by hydroxides is called hydroxide alkalinity or caustic alkalinity, caused by carbonate is carbonate alkalinity and caused by bicarbonate is called bicarbonate alkalinity.

$$HCO_3^- = \frac{50{,}000\left\{\left(\frac{A}{50{,}000} + [H^+]\right) - \frac{K_w}{[H^+]}\right\}}{1 + \left(\frac{2\,K_2}{[H^+]}\right)}$$

$$CO_3^{2-} = \left(\frac{2\,K_2}{[H^+]}\right)(HCO_3^-)$$

Where, A = total alkalinity, mg/L as $CaCO_3$

K_2 = second dissociation constant of carbonic acid = 4.68×10^{-11} at 25^0C

K_w = ionization constant of water = 1×10^{-14} at 25^0C

HCO_3^- = Bicarbonate alkalinity in mg/L as $CaCO_3$

CO_3^{2-} = Carbonate alkalinity in mg/L as $CaCO_3$

Relation between Hardness and Alkalinity

If alkalinity > Total hardness

Carbonate hardness, mg/L as $CaCO_3$ = Total hardness, mg/L as $CaCO_3$ ($TH = CH$)
Non-carbonate hardness, mg/L as $CaCO_3$ = 0 ($NCH = 0$)

If alkalinity < Total hardness

Carbonate hardness, mg//L as $CaCO_3$ = Alkalinity, mg/L as $CaCO_3$ (CH = Alkalinity)
Non-carbonate hardness, mg/L as $CaCO_3$ = Total hardness, mg/L as $CaCO_3$ – Carbonate hardness, mg/L as $CaCO_3$ ($NCH = TH - CH$)

Removal of Hardness of water

Temporary Hardness: By boiling and by addition of Lime
Permanent Hardness: Lime-soda process, Zeolite or base-exchange process, Demineralisation process.

Lime-Soda Softening

Chemical precipitation is among the most common methods used to soften water. Lime (calcium hydroxide, $Ca(OH)_2$) is used to remove chemicals that cause carbonate hardness. Soda ash (sodium carbonate, Na_2CO_3) is used to remove chemicals that cause non-carbonate hardness. Precipitation is based on the following two solubility reactions:

$$Ca^{2+} + CO_3^{2-} \rightleftharpoons CaCO_3(s)$$

$$Mg^{2+} + 2OH^- \rightleftharpoons Mg(OH)_2(s)$$

The objective is to precipitate the calcium as $CaCO_3$ and the magnesium as $Mg(OH)_2$. In order to precipitate $CaCO_3$, the pH of the water must be raised to about 10.3. To precipitate magnesium, the pH must be raised to about 11.

Neutralization of Carbonic Acid

$$CO_2 + \mathbf{Ca(OH)_2} \rightleftharpoons CaCO_3(s) + H_2O$$

Precipitation of Carbonate Hardness

$$Ca^{2+} + 2HCO_3^- + \mathbf{Ca(OH)_2} \rightleftharpoons 2CaCO_3(s) + 2H_2O$$

$$Mg^{2+} + 2HCO_3^- + \mathbf{Ca(OH)_2} \rightleftharpoons MgCO_3 + CaCO_3(s) + 2H_2O$$

$$MgCO_3 + \mathbf{Ca(OH)_2} \rightleftharpoons Mg(OH)_2(s) + CaCO_3(s)$$

Precipitation of Noncarbonate Hardness Due to Calcium

$$Ca^{2+} + \mathbf{Na_2CO_3} \rightleftharpoons CaCO_3(s) + 2Na^+$$

Precipitation of Noncarbonate Hardness Due to Magnesium

$$Mg^{2+} + \mathbf{Ca(OH)_2} \rightleftharpoons Mg(OH)_2(s) + Ca^{2+}$$

$$Ca^{2+} + \mathbf{Na_2CO_3} \rightleftharpoons CaCO_3(s) + 2Na^+$$

• Summary of softening reactions. (*Note:* The chemical added is printed in bold type. The precipitate is designated by (s). The arrow indicates where a compound formed in one reaction is used in another reaction.)

$$\text{Lime required} = CO_2 + HCO_3^- + Mg^{2+} + \text{excess}$$

$$\text{Soda ash required} = Ca^{2+} + Mg^{2+} - \text{alkalinity}$$

Lime-soda softening cannot produce a water completely free of hardness because of the solubility of $CaCO_3$ and $Mg(OH)_2$, the physical limitations of mixing and contact, and the lack of sufficient time for the reactions to go to completion. Thus, the minimum calcium hardness that can be achieved is about 30 mg/L as $CaCO_3$, and the minimum magnesium hardness is about 10 mg/L as $CaCO_3$. Magnesium in excess of about 40 mg/L as $CaCO_3$ forms scales on heat exchange elements in hot water heaters. Because of the expense of removing magnesium, we normally remove only that magnesium which is in excess of 40 mg/L as $CaCO_3$. For magnesium removals less than 20 mg/L as $CaCO_3$, the basic excess of lime mentioned above is sufficient to ensure good results. For magnesium removals between 20 and 40 mg/L as $CaCO_3$, we must add an excess of lime equal to the magnesium to be removed. For magnesium removals greater than 40 mg/L as $CaCO_3$, the excess lime we need to add is 40 mg/L as $CaCO_3$. Addition of excess lime in amounts greater than 40 mg/L as $CaCO_3$ does not appreciably improve the reaction kinetics. The chemical additions as $CaCO_3$ to soften water may be summarized as follows:

Step	Chemical addition[a]	Reason
Carbonate hardness		
1.	Lime = CO_2	Destroy H_2CO_3
2.	Lime = HCO_3^-	Raise pH: convert HCO_3^- to CO_3^{2-}
3.	Lime = Mg^{2+} to be removed	Raise pH: precipitate $Mg(OH)_2$
4.	Lime = required excess	Drive reaction
Noncarbonate hardness		
5.	Soda = noncarbonate hardness to be removed	Provide CO_3^{2-}

[a] The terms "Lime =" and "Soda =" refer to mg/L of $Ca(OH)_2$ and Na_2CO_3 as $CaCO_3$ equal to mg/L of ion (or gas in the case of CO_2) as $CaCO_3$.

Question: The hydrogen-ion concentration or pH value of water is a measure of degree of acidity or alkalinity of water. For water at 21°C, Water becomes acidic when concentration of H ions is increased and alkaline when concentration of H ions is decreased.

Solution:

For pure water, $pH = 7$
$pOH = -\log[OH^-]$
$pH + pOH = 14$
For water with maximum acidity, pH value is zero, while for water with maximum alkalinity, pH value is 14. For potable waters, the pH value should between 6 and 9, and preferable between 7 and 8.5.

Question: If the $pH = 9.5$, what is the [OH-] concentration? (PGCB – 2019)

Solution:

$pH + pOH = 14$

$pOH = 14 - 9.5 = 4.5$

$pOH = -\log\ [OH^-]$

$[OH^-] = 10^{-4.5} = 3.16 \times 10^{-5}$ mol/L

Question: Find the hydrogen ion concentration and hydroxide ion concentration in tomato juice having pH of 4.1 (GTCL – 2018)

Solution:

$pH = -\log\ [H^+]$

$4.1 = -\log\ [H^+]$

$[H^+] = 10^{-4.1} = 7.94 \times 10^{-5}$ mol/L
$pH + pOH = 14$

$pOH = 14 - 4.1 = 9.9$

$pOH = -\log\ [OH^-]$

$[OH^-] = 10^{-9.9} = 1.16 \times 10^{-10}$ mol/L

Question: 100 gm H_2SO_4 mixed with 100L water, determine the value of pH [MW = 98] .Equation $H_2SO_4 = 2\,[H^+] + SO_4^{2-}$ (NPCBL – 2019)

Solution:

$$\text{mol of } H_2SO_4 = \frac{\text{Weight}}{\text{Molecular Weight}} = \frac{100}{98} = 1.02 \text{ mol}$$

$$\text{Molarity}, M = \frac{\text{mol}}{\text{L}} = \frac{1.02}{100} = 0.0102\,M$$

$$H_2SO_4 = 2\,[H^+] + SO_4^{2-}$$

Concentration of $[H^+] = 2 \times 0.0102 = 0.0204\,M$

$pH = -\log\,[H^-] = -\log\,[0.0204] = 1.69$

Question: A water contains 100.0 mg/L CO_3^{2-} and 75.0 mg/L HCO_3^- at a pH of 10. Calculate the alkalinity exactly at 25° C. Approximate the alkalinity by ignoring $[OH^-]$ and $[H^+]$

Solution:

First convert CO_3^{2-}, HCO_3^-, OH^- and H^+ to mg/L as $CaCO_3$
The equivalent weights are,

$CO_3^{2-}: MW = 60, n = 2, EW = 30$
$HCO_3^-: MW = 61, n = 1, EW = 61$
$H^+: MW = 1, n = 1, EW = 1$
$OH^-: MW = 17, n = 1, EW = 17$

And the concentration of $H^+$and OH^- is calculated as follows: $pH = 10$

$[H^+] = 10^{-10}\,M$

mg/L = $(10^{-10}$ moles/L)(1 g/mole) (10^3 mg/g) = 10^{-7}

$$[OH^-] = \frac{K_w}{[H^+]} = \frac{10^{-14}}{10^{-10}} = 10^{-4} \text{ moles/L}$$

mg/L = $(10^{-4}$ moles/L)(17 g/mole) (10^3 mg/g) = 1.7

Taking the equivalent weight of $CaCO_3$ to be 50

$$CO_3^{2-} = 100\left(\frac{50}{30}\right) = 167$$

$$HCO_3^- = 75\left(\frac{50}{61}\right) = 61$$

$$H^+ = 10^{-7}\left(\frac{50}{1}\right) = 5 \times 10^{-6}$$

$$OH^- = 1.7\left(\frac{50}{17}\right) = 5$$

Alkalinity = $61 + 167 + 5 - (5 \times 10^{-6}) = 233$ mg/L as $CaCO_3$
Approximate Alkalinity = $61 + 167 = 228$ mg/L as $CaCO_3$

Question: Determine the total hardness as $CaCO_3$, of a sample of water that has calcium content of 28 mg/L and magnesium content of 9 mg/L as the ion.

Solution:

Total hardness (mg/L as $CaCO_3$ or meq/L) = Calcium hardness + Magnesium hardness

$$\text{Total hardness} = \frac{Ca^{2+} \times 50}{20} + \frac{Mg^{2+} \times 50}{12}$$

$$TH = \frac{28 \times 50}{20} + \frac{9 \times 50}{12} = 107.5 \text{ mg/L as } CaCO_3$$

Question: A water sample contains 110 mg/L alkalinity as $CaCO_3$ and 105 mg/L total hardness as $CaCO_3$. What is the carbonate and non-carbonate hardness of the sample?

Solution:

Here, alkalinity > Total hardness

$CH = \text{Total hardness} = 110 \text{ mg/L as } CaCO_3$

$NCH = 0$

Question: The alkalinity of a water sample is 80 mg/L as $CaCO_3$. If the total hardness of the water sample is 112 mg/L as $CaCO_3$, what is the carbonate and non-carbonate hardness, in mg/L as $CaCO_3$?

Solution:

Here, alkalinity < Total hardness

$CH = \text{Alkalinity} = 80 \text{ mg/L as } CaCO_3$

$\text{Non} - \text{carbonate hardness} = TH - CH = 112 - 80 = 32 \text{ mg/L as } CaCO_3$

Question: A water sample has a total hardness of 250 mg/L as $CaCO_3$ and a total alkalinity of 180 mg/L. What soda ash will be required to remove the noncarbonated hardness in mg/L?

Solution:

Here, alkalinity < Total hardness

$CH = \text{Alkalinity} = 180 \text{ mg/L as } CaCO_3$

$\text{Non} - \text{carbonate hardness} = TH - CH = 250 - 180 = 70 \text{ mg/L as } CaCO_3$

$$\text{Soda ash required } (Na_2CO_3) = 70 \times \frac{106}{100} = 74.2 \text{ mg/L soda ash}$$

Question: The analysis of water from a well shows the following results in mg/L; $Ca^{2+} = 65$, $Mg^{2+} = 51$, $Na^{+} = 100$, $K^{+} = 25$, $HCO_3^{-} = 248$, $SO_4^{2-} = 220$, $Cl^{-} = 18$, $CO_3^{2-} = 240$. Find Total hardness (TH), Carbonate Hardness (CH) and Non-Carbonate Hardness (NCH) in mg/L as $CaCO_3$.

Solution:

$$\text{Total hardness} = \frac{Ca^{2+} \text{ x } 50}{20} + \frac{Mg^{2+} \text{ x } 50}{12}$$

$$TH = \frac{65 \text{ x } 50}{20} + \frac{51 \text{ x } 50}{12} = 375 \text{ mg/L as } CaCO_3$$

$$\text{Alkalinity} = [HCO_3^{-}] + [CO_3^{2-}] + [OH^{-}] - [H^{+}]$$

$$\text{Alkalinity} = \frac{248 \text{ x } 50}{61} + \frac{240 \text{ x } 50}{30} = 203.278 + 400 = 603.27 \text{ mg/L as } CaCO_3$$

Here, Alkalinity > Total hardness

Hence, Carbonate hardness (CH) = Total hardness = 488 mg/L as $CaCO_3$

Non − carbonate hardness $(NCH) = 0$

Question: The analysis of water from the bore shows the following results in mg/L as the ion. $Ca^{2+} = 60$, $Mg^{2+} = 48$, $Na^{+} = 103.5$, $K^{+} = 19.5$, $HCO_3^{-} = 244$, $SO_4^{2-} = 220.8$, $Cl^{-} = 78.1$. Find out the total hardness, Carbonate hardness and non-carbonate hardness in mg/L as $CaCO_3$. (WARPO − 2017, DMTCL − 2019)

Solution:

$$\text{Total hardness} = \frac{Ca^{2+} \text{ x } 50}{20} + \frac{Mg^{2+} \text{ x } 50}{12}$$

$$TH = \frac{60 \text{ x } 50}{20} + \frac{48 \text{ x } 50}{12} = 350 \text{ mg/L as } CaCO_3$$

$$\text{Alkalinity} = [HCO_3^{-}] + [CO_3^{2-}] + [OH^{-}] - [H^{+}]$$

$$\text{Alkalinity} = \frac{244 \text{x } 50}{61} = 200 \text{ mg/L as } CaCO_3$$

Here, Total hardness > Alkalinity

Hence, Carbonate hardness (CH) = Alkalinity = 200 mg/L as $CaCO_3$

Non − carbonate hardness (NCH) = Total hardness (TH) − Carbonate hardness (CH)

$NCH = 350 - 200 = 150$ mg/L as $CaCO_3$

Question: A water has an alkalinity of 200 mg/L as $CaCO_3$. The Ca^{2+} concentration of 160 mg/L as the ion, and the Mg^{2+} concentration is 40 mg/L as the ion. The P^H is 8.1. Find the total, carbonate and noncarbonated hardness. (PGCB – 2019)

Solution:

$$\text{Total hardness} = \frac{Ca^{2+} \text{ x } 50}{20} + \frac{Mg^{2+} \text{ x } 50}{12} + \frac{Sr^{2+} \text{ x } 50}{43.8}$$

$$TH = \frac{160 \text{ x } 50}{20} + \frac{40 \text{ x } 50}{12} = 567 \text{ mg/L as } CaCO_3$$

Where 50 is the equivalent weight of $CaCO_3$. By definition, the carbonate hardness is the lesser of the total hardness or the alkalinity. Since, in this case, the alkalinity is less than the total hardness, the carbonate hardness (CH) is equal to 200 mg/L as $CaCO_3$.

Non – carbonate hardness $= TH - CH = 567 - 200 = 367$ mg/L as $CaCO_3$

Question: Laboratory analysis of water sample. All concentrations are "as substance". $Ca^{2+} = 74$ mg/L, $Mg^{2+} = 18.3$ mg/L, $Na^{+} = 27.6$ mg/L, $K^{+} = 39.1$ mg/L, $P^H = 7.8$; $HCO_3^- = 274.5$ mg/L, $SO_4^{2-} = 72$ mg/L, $Cl^- = 49.7$ mg/L. Determine i) Hardness of water in mg/L of $CaCO_3$? ii) Amount of lime needed to remove hardness by $CaCO_3$? (SGFL – 2017)

Solution:

$$\text{Total hardness} = \frac{Ca^{2+} \text{ x } 50}{20} + \frac{Mg^{2+} \text{ x } 50}{12}$$

$$TH = \frac{74 \text{ x } 50}{20} + \frac{18.3 \text{ x } 50}{12} = 261.25 \text{ mg/L as } CaCO_3$$

$$HCO_3^- = \frac{274.5 \text{ x } 50}{61} = 225 \text{ mg/L as } CaCO_3$$

Total alkalinity $= CO_3^{2-} + HCO_3^- + OH^- - H^+$

For nearly neutral water (pH around 6 – 8) the concentration of H^+ and OH^- are insignificant and alkalinity is determined entirely by the carbonates,

Alkalinity $= CO_3^{2-} + HCO_3^- = 225$ mg/L as $CaCO_3$

Lime required $= CO_2 + HCO_3^- + Mg^{2+} +$ excess

$$HCO_3^- = 274.5 \text{ x } \frac{50}{61} = 225 \text{ mg/L as } CaCO_3$$

$$Mg^{2+} = 18.3 \text{ x } \frac{50}{12} = 76.25 \text{ mg/L as } CaCO_3$$

Step	Dose (mg/L as $CaCO_3$)
Lime = CO_2	0
Lime = HCO_3^-	225
Lime = $Mg^{2+} - 40 = 76.25 - 40 =$	36.25
Lime = excess	36.25

Excess lime $= 36.25$ mg/L as $CaCO_3$

Total Lime required = 225 + (76.25 − 40) + 36.25 + 0 = 297.5 mg/L as $CaCO_3$

The amount of lime to add is 297.5 mg/L as $CaCO_3$. The excess chosen was equal to the difference between the Mg^{2+} concentration and 40 since that difference was between 20 and 40, that is, $Mg^{2+} = 76.25 - 40 = 36.25$.

Question: Laboratory test shows $Ca^{2+} = 40$ mg/L. Total carbonate hardness = 3 meq/L. Assume carbonate hardness only due to HCO_3^-; Non-carbonate hardness = 1 meq/L. Determine total hardness and Mg^{2+} and HCO_3^- in mg/L. (BWDB – 2019)

Solution:

$$TH = CH + NCH = 3 + 1 = 4 \text{ meq/L}$$

$$Ca^{2+} = \frac{40 \text{ mg/L}}{20 \text{ mg/meq}} = 2 \text{ meq/L}$$

$$TH = Mg^{2+} + Ca^{2+}$$

$$Mg^{2+} = 4 - 2 = 2 \text{ meq/L} = 12.2 \text{ x } 2 = 24.4 \text{ mg/L}$$

$$CH = HCO_3^- = 3 \text{ meq/L} = 3 \text{ x } 61 = 183 \text{ mg/L}$$

Question: The pH is 10 and total alkalinity is 332 mg/L as $CaCO_3$. Find the value of carbonate and bicarbonate alkalinity and carbonate and bicarbonate concentration. (GTCL – 2016)

Solution:

$$\text{Bicarbonate alkalinity (mg/L as } CaCO_3) = \frac{50{,}000\left\{\left(\frac{A}{50{,}000} + [H^+]\right) - \frac{K_w}{[H^+]}\right\}}{1 + \left(\frac{2K_2}{[H^+]}\right)}$$

$$HCO_3^- = \frac{50{,}000\left[\left(\frac{332}{50{,}000} + 10^{-10}\right) - \frac{10^{-14}}{10^{-10}}\right]}{\left[1 + \left(\frac{2 \text{ x } 4.68 \text{ x } 10^{-11}}{10^{-10}}\right)\right]} = 168.90 \text{ mg/L as } CaCO_3$$

$$\text{Carbonate alkalinity (mg/L as } CaCO3) = \left(\frac{2K_2}{[H^+]}\right)(HCO_3^-)$$

$$CO_3^{2-} = \left(\frac{2 \text{ x } 4.68 \text{ x } 10^{-11}}{10^{-10}}\right) \text{ x } 168.90 = 158.09 \text{ mg/L as } CaCO_3$$

Because the alkalinity is reported as mg/L as $CaCO_3$, it must be converted to mg/L

$$\text{Molar Concentration, } [HCO_3^-] = 168.90 \text{ mg/L x } \frac{61 \text{ mg/meq}}{50 \text{ mg/meq}} \text{ x } \frac{1}{61 \text{ g/mol x } 1000 \text{ mg/g}}$$

$$[HCO_3^-] \text{ concentration} = 3.378 \text{ x } 10^{-3} \text{ moles/L}$$

$$\text{Molar Concentration, } [CO_3^{2-}] = 158.09 \text{ mg/L x } \frac{30 \text{ mg/meq}}{50 \text{ mg/meq}} \text{ x } \frac{1}{30 \text{ g/mol x } 1000 \text{ mg/g}}$$

$$[CO_3^{2-}] \text{ concentration} = 3.1618 \text{ x } 10^{-3} \text{ moles/L}$$

Question: A sample of water at pH 10.0 has 32.0 mg/L of CO_3^{2-} and 56.0 mg/L of HCO_3^-. Find the alkalinity as $CaCO_3$

$$CO_3^{2-} = 32\left(\frac{50}{30}\right) = 53.3 \text{ mg/L as } CaCO_3$$

$$HCO_3^- = 56\left(\frac{50}{61}\right) = 49.50 \text{ mg/L as } CaCO_3$$

$$H^+ = 10^{-7}\left(\frac{50}{1}\right) = 5 \text{ x } 10^{-6}$$

$$[H^+] = 10^{-10} \text{ mol/L}$$
$$\text{mg/L} = (10^{-10} \text{ moles/L})(1 \text{ g/mole})\ (10^3 \text{ mg/g}) = 10^{-7}$$
$$H^+ = 10^{-7}\left(\frac{50}{1}\right) = 5 \text{ x } 10^{-6} \text{ mg/L as } CaCO_3$$

$$[OH^-] = \frac{K_w}{[H^+]} = \frac{10^{-14}}{10^{-10}} = 10^{-4} \text{ moles/L}$$
$$\text{mg/L} = (10^{-4} \text{ moles/L})(17 \text{ g/mole})\ (10^3 \text{ mg/g}) = 1.7$$
$$OH^- = 1.7\left(\frac{50}{17}\right) = 5 \text{ mg/L as } CaCO_3$$

Total alkalinity $= CO_3^{2-} + HCO_3^- + OH^- - H^+$

Alkalinity $= 53.3 + 45.9 + 5 - 5 \text{ x } 10^{-6} = 104.2$ mg/L as $CaCO_3$

Question: An analysis of a sample of water with pH 7.5 has produced the following concentrations (mg/L)

Cations	mg/L	Anions	mg/L
Ca^{2+}	80	Cl^-	100
Mg^{2+}	30	SO_4^{2-}	201
Na^+	72	HCO_3^-	165
K^+	6		

Find the total hardness, the carbonate hardness, the noncarbonated hardness and the alkalinity all expressed as $CaCO_3$. Find the total dissolved solids in mg/L.

Solution:

Water analysis,

Ion	Mg/L	MW	n	mg/meq	meq/L	mg/L as $CaCO_3$
Ca^{2+}	80	40.1	2	20.05	3.99	199.5
Mg^{2+}	30	24.3	2	12.15	2.47	123.5
Na^+	72	23.0	1	23.0	3.13	156.5
K^+	6	39.1	1	39.1	0.15	7.7
Cl^-	100	35.5	1	35.5	2.82	140.8
SO_4^{2-}	201	96.1	2	48.05	4.18	209.2
HCO_3^-	165	61.0	1	61.0	2.70	135.2

Total hardness, $TH = Mg^{2+} + Ca^{2+} = 199.5 + 123.5 = 323.0$ mg/L as $CaCO_3$

Carbonate hardness, $CH = HCO_3^- = 135.2$ mg/L as $CaCO_3$

Non − carbonate hardness, $NCH = TH - CH = 323 - 135.2 = 187.8$ mg/L as $CaCO_3$

Total alkalinity $= CO_3^{2-} + HCO_3^- + OH^- - H^+ = 135.2$ mg/L as $CaCO_3$

Total dissolved solids, TDS = 199.5 + 123.5 + 156.5 + 7.7 + 140.8 + 209.2 + 135.2 = 654 mg/L

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