

GATEFLIX

**ENVIRONMENTAL
ENGINEERING**

**For
CIVIL ENGINEERING**

ENVIRONMENTAL ENGINEERING

SYLLABUS

Water Requirements: Quality standards, basic unit processes and operations for water treatment. Drinking water standards, water requirements, basic unit operations and unit processes for surface water treatment, distribution of water. Sewage and sewerage treatment, quality and characteristics of wastewater. Primary, secondary and tertiary treatment of wastewater, sludge disposal, effluent discharge standards. Domestic wastewater treatment, quantity of characteristics of domestic wastewater, primary and secondary treatment unit operations and unit processes of domestic wastewater, sludge disposal.

Air Pollution : Types of pollutants, their sources and impacts, air pollution meteorology, air pollution control, air quality standards and limits.

Municipal Solid Wastes : Characteristics, generation, collection and transportation of solid wastes, engineered systems for solid waste management (reuse/recycle, energy recovery, treatment and disposal).

Noise Pollution : Impacts of noise, permissible limits of noise pollution, measurements of noise and control of noise pollution.

ANALYSIS OF GATE PAPERS

| Exam Year | 1 Mark Ques. | 2 Mark Ques. | Total |
|------------|--------------|--------------|-------|
| 2003 | 4 | 9 | 22 |
| 2004 | 3 | 9 | 21 |
| 2005 | 4 | 8 | 20 |
| 2006 | 3 | 6 | 15 |
| 2007 | 3 | 6 | 15 |
| 2008 | 2 | 6 | 14 |
| 2009 | 2 | 6 | 14 |
| 2010 | 3 | 3 | 9 |
| 2011 | 3 | 3 | 9 |
| 2012 | 2 | 4 | 10 |
| 2013 | 2 | 3 | 8 |
| 2014 Set-1 | 3 | 3 | 9 |
| 2014 Set-2 | 2 | 4 | 10 |
| 2015 Set-1 | 3 | 2 | 6 |
| 2015 Set-2 | 2 | 4 | 10 |
| 2016 Set-1 | 4 | 3 | 10 |
| 2016 Set-2 | 5 | 4 | 13 |
| 2017 | 3 | 4 | 11 |

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1

WATER DEMAND, ITS SOURCE & CONVEYANCE

WATER DEMAND, ITS SOURCE & CONVEYANCE

To design a water supply scheme, we must first estimate the population for which the scheme should be designed. The scheme up to some predetermined future date.

1.1 DESIGN PERIODS

- A water supply scheme includes huge and costly structures (such as dams, reservoirs) which cannot be replaced or increased in their capacities, easily and conveniently. In order to avoid these future complications of expansion, the various components of a water supply scheme are purposely made larger, so as to satisfy the community needs for a reasonable number of years to come.
- This future period or the number of years for which a provision is made in designing the capacities of various components of the water supply scheme is known as **design period**.
- The design period should neither be too long nor should it be too short. It should not exceed the useful life of the component structure.

| Units | Design Period |
|---|---------------|
| Water treatment units | 15 years |
| Pipe connections to the several treatment units | 30 years |
| Service reservoirs (overhead of ground level) | 15 years |
| Distribution System | 30years |

1.2 POPULATION FORECASTING

Water demand is assessed on the basis of future population. The future population is assessed as discussed below.

1.2.1 POPULATION GROWTH

There are three main factors responsible for changes in population :-

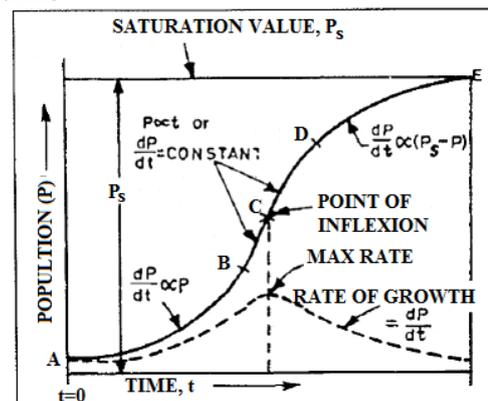
- Births
- Deaths
- Migrations

- Population forecasting is done by mathematical formulae and graphical solutions based upon previous population records

1.2.2 GROWTH CURVE

The population would probably follow the growth curve characteristics of living things within limited space or with limited economic opportunity. The curve is S-shaped as shown below and is known as **logistic curve**.

- The curve represents early growth AB at an increasing rate (i.e., geometric or log growth, $\frac{dP}{dt} \propto P$); and late growth DE at a decreasing rate [i.e., 1st order curve, $\frac{dP}{dt} \propto (P_s - P)$] as the situation value (P_s) is approached.
- The transitional middle curve BD follows an arithmetic increase (i.e., $\frac{dP}{dt} = \text{constant}$). What the future holds for a given population, depends upon as to where the point lies on the growth curve at a given time.



1.3 POPULATION FORECASTING METHODS

The various methods which are generally adopted for estimating future population by engineers are not exact, and they are all based on the laws of probability, and thus, only approximate estimates for the possible future population can be made. The various methods followed are as discussed below:

1. Arithmetic Increase Method : This method is based upon the assumption that the population increases at a constant rate

$$\text{i.e., } \frac{dp}{dt} = \text{constant} = k \quad \text{or}$$

$$dp = kdt \quad \text{or}$$

$$\int_{P_1}^{P_2} dp = \int_{t_1}^{t_2} kdt = k(t_2 - t_1)$$

where, $t_2 - t_1$ = number of decades

Forecasted population after n decades from the present (i.e., last known census) is given by

$$P_a = P_o + n\bar{x}$$

Where,

P_n = prospective population after n decades from present.

P_o = population at present

n = number of decades between now and future.

\bar{x} = average (arithmetic mean) of population increase in the known decades.

Example 1

The population of 5 decades from 1930 to 1970 are given in table. Find out the population after one and six decades beyond the last known decade by using arithmetic increase method.

| Year | Population |
|------|------------|
| 1930 | 25,000 |
| 1940 | 28,000 |
| 1950 | 34,000 |
| 1960 | 42,000 |
| 1970 | 47,000 |

Solution

| Year | Population | Increase in Population (x) |
|-------|------------|----------------------------|
| 1930 | 25,000 | |
| 1940 | 28,000 | 3000 |
| 1950 | 34,000 | 6000 |
| 1960 | 42,000 | 8000 |
| 1970 | 47,000 | 5000 |
| Total | | 22000 |

Average increase per decades (\bar{x})

$$(\bar{x}) = 22000/4 = 5,500$$

(a) Population after 1 decade beyond 1970

$$\begin{aligned} P_{1980} &= P_{1970} + 1 \cdot \bar{x} \\ &= 47,000 + 5,500 \\ &= 52,500 \end{aligned}$$

(b) Population after six decade beyond 1970

$$\begin{aligned} P_{2030} &= P_{1970} + 6 \cdot \bar{x} \\ &= 47,000 + 6 \times 5,500 \\ &= 80,000 \end{aligned}$$

2. Geometric Increase Method: In this method, the per decade percentage increase or percentage growth rate (r) is assumed to be constant, and the increase is compounded over the existing population every decade. This method is also known as uniform increase method. The forecasted population (P_n) after n decades is given by

$$P_n = P_o \left(1 + \frac{r}{100} \right)^n$$

Where,

P_o = Population at the end of last known census.

r = Assumed growth rare (%)

r can be computed in several ways from the past known population data.

$$(a) \quad r = \sqrt[n]{\frac{P_2}{P_1}} - 1$$

Where,

P_1 = Initial known population

P_2 = Final known population,

N = Number of decades between P_1 & P_2

(b)

$$r = \frac{\text{increase in population}}{\text{Original population}} \times 100$$

For knowing each decades r_1, r_2, \dots, r_n the average value of r can be found by

(i) Arithmetic average method

$$r = \frac{r_1 + r_2 + \dots + r_n}{n}$$

(ii) Geometric average method

$$r = (r_1 \times r_2 \times r_3 \times \dots \times r_n)^{1/n}$$

Note: The design engineers in the field adopt arithmetic average method since it gives more values than geometric average method. However the "GOI Manual on Water Treatment" recommends 'Geometric mean' method

Example 2

Determine the future population of a town by the geometric increase method for the year 2011, as given in the following data:

| Year | Population |
|-----------|------------|
| 1951 | 93 |
| 1961 | 111 |
| 1971 | 132 |
| 1981 | 161 |
|2011 |? |

Solution

WATER DEMAND, ITS SOURCE AND CONVEYANCE

| Year | 1951 | 1961 | 1971 | 1981 |
|--------------------------------------|------|---------------------------------------|--|--|
| Population (in thousand) | 93 | 111 | 132 | 161 |
| increase in population (in thousand) | | 18 | 21 | 29 |
| % increase in population | | $\frac{18}{93} \times 100$ = 19.35 | $\frac{21}{111} \times 100$ = 18.92 | $\frac{29}{132} \times 100$ = 21.97 |

Constant growth rate, assumed for future

r = geometric mean of past growth rate

$$r = \sqrt[3]{19.35 \times 19.82 \times 21.97}$$

r = 20.23% per decade

The population after n decades is

$$P_n = P_o \left(1 + \frac{r}{100} \right)^n$$

P_{2011} = population after three decades from

$$1981 P_{2011} = P_{1981} \left(1 + \frac{20.03}{100} \right)^3$$

$$P_{2011} = 161(1.2003)^3$$

$$P_{2011} = 278.41 \text{ (in thousand)}$$

$$P_{2011} = 278417$$

3. Incremental Increase Method (or Method of Varying Increment)

- In this method, growth rate is not assumed to be constant as in the arithmetic or geometric progression methods, but is progressively increasing or decreasing, depending upon whether the average of the incremental increases in the past data is positive or negative.
- The population for future decade is found out by adding the mean arithmetic increase (\bar{x}) to be last known population as in arithmetic increase method and this is added to the average of the incremental increases \bar{y} . Once for the first decade, twice for the second decade, and so on.
- The population after n decades from present. (i.e., last known census) is given by

$$P_n = P_o + n\bar{x} + \frac{n(n+1)}{2}\bar{y}$$

Where,

\bar{x} = average increase of population of known decades

\bar{y} = average of incremental increase of the known

This method will give results, somewhere between the result given by arithmetic increase method and geometric increase method and thus considered to be given quite satisfactory results.

Note: The geometric progression method, gives highest values of forecasted population. This method is suitable for new younger cities expanding at faster rate. For old cities,

the arithmetic method may be better, although incremental method is considered to be the best for any city whether old or new.

Example 3

In a town, it has been decided to provide 200/per head per day in the 21st century. Estimate the domestic water requirements of this town in the year 2000 AD by projecting the population of the town by incremental increase method.

| Year | 1940 | 1950 | 1960 | 1970 | 1980 |
|----------------|--------------|--------------|--------------|--------------|--------------|
| popul ation | 2379 8624 | 4697 8325 | 5478 6437 | 6346 7823 | 6907 7421 |

Solution

| Year | Population | Increase in population | Increment over the increase, i.e. incremental increase. |
|--------------|------------|------------------------|---|
| 1940 | 23798624 | 23179701 | (-)15371589 |
| 1950 | 46978325 | 7808112 | (+) 873274 |
| 1960 | 54786437 | 8681386 | (-) 3071788 |
| 1970 | 63467823 | 5609598 | |
| 1980 | 69077421 | | |
| Total | | 45278797 | (-)17570103 |

Average per decade

$$\bar{x} = 11319699$$

$$\bar{y} = \frac{17570103}{3}$$

$$\bar{y} = (-)5856701$$

Expected population at the end of year 2000 i.e., after 2 decades from 1980

$$= p_0 + 2\bar{x} + \frac{2 \times 3 - 1}{2} \bar{y}$$

$$= 69077421 + 2 \times 11319699 - 3 \times 5856701$$

$$= 74146716$$

Water requirement in 2000 AD @ 200 // head/day

$$= 200 \times 74146716 // \text{day}$$

$$= 14829 \times 10^6 // \text{day}$$

4. The logistic Curve Method

This method was given by P.F. Verhulst. The population at any time t from the start is given by

$$P = \frac{P_s}{1 + m \log_e^{-1}(nt)}$$

P_s = saturation population

M = constant

5. Decreasing rate of growth

- This method is applicable only when the rate of growth shows a downward trend.
- Since the rate of increase in population go on reducing, as the cities reach towards saturation, a method which makes use of the decrease in the percentage increase, is many a times used and gives quit rational results.
- In this method, the average decrease in the percentage increase is worked out, and is then subtracted from the latest percentage increase for each successive decade as explained in example blow

Example 4

The census record of a particular town shows the population figures as follows:

| Year | Population |
|------|------------|
| 1960 | 55,500, |
| 1970 | 63,700 |
| 1980 | 71,300 |
| 1990 | 79,500 |

Estimate the population for the year 2020 by decreasing rate growth.

Solution

The decreasing rate of growth method is as follows

Avg. Value of

| Year | pop | Incr in pop. | % Incr in pop. (r) | Decr in | % increase (r') |
|------|--------|--------------|--------------------|---------|-----------------|
| 1960 | 55,500 | 8200 | 14.77 | | |
| 1970 | 63,700 | 7600 | 11.93 | | 2.84 |
| 1980 | 71,300 | 8200 | 11.5 | | 0.43 |
| 1990 | 79,500 | | | | |

$$r' = \frac{2.84 + 0.43}{2} = 1.635$$

$$r = 11.5$$

$$P_{2000} = P_{1990} + \left(\frac{r - r'}{100} \right) \times P_{1990}$$

$$= 79,500 + \left(\frac{11.5 - 1.635}{100} \right) \times 79,500$$

$$= 87,343$$

$$P_{2010} = P_{2000} + \left(\frac{r - 2r'}{100} \right) \times P_{2000}$$

$$= 87,343 + \left(\frac{11.5 - 2 \times 1.635}{100} \right) \times 87,343$$

$$= 94,531$$

$$P_{2020} = P_{2010} + \left(\frac{r - 3r'}{100} \right) \times P_{2010}$$

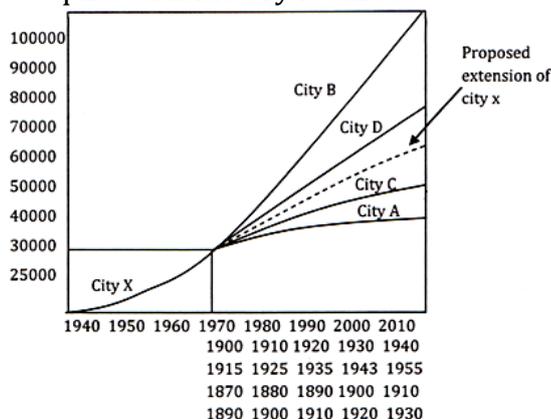
$$= 94,531 + \left(\frac{11.5 - 3 \times 1.635}{100} \right) \times 94,531$$

$$= 1,00,765$$

The population for the year 2020 is **1,00,765**

6. Comparative Graphical Method

Cities of similar conditions and characteristics are selected which have grown in similar fashion in the past as that of the city under consideration and their graph is plotted and then mean graph is also plotted. This method gives quite satisfactory results.



1.4 WATER DEMANDS

Whenever an engineer is given the duty to design a water supply scheme for a

particular section of the community, the first study is to consider the demand and then the second requirement is to find sources to fulfill that demand.

1.4.1 VARIOUS TYPES OF WATER DEMANDS ARE

Domestic Water Demand:

This includes the water required in private building for drinking, cooking, bathing, gardening purposes etc which may vary according to the living condition of the consumers.

- The total domestic water consumption usually amounts to 50 to 60% of the total water consumption.
- The IS code lays down a limit on domestic water consumption between 135 to 225 l/h/d.
- Under ordinary conditions (as per I.S. code) the minimum domestic water demand for a town with full flushing system should be taken at 200 l/h/d although it can be reduced to 135 l/h/d for economically weaker sections and LIG colonies (Low Income Group) depending upon prevailing conditions.

A) Institutional and Commercial Water Demand:

On an average, a per capita demand of 20 l/h/d is usually considered to be enough to meet such commercial and institutional water requirements, although of course, this demand may be as high as 50 l/h/d for highly commercialized cities:

The individual requirements would be as follows:

- Schools/Colleges** : 45 to 135 lpcd
- Offices** : 45 lpcd
- Restaurants** : 70 lpcd
- Cinema and theater** : 15 lpcd
- Hotels** : 180 lpcd
- Hospitals** : 340 lpcd (when beds is less than 100), & 450 lpcd (beds exceeding 100).

B) Industrial Water Demand:

The 'industrial water demand', represents the water demand of industries, which are either existing or likely to be started in the city for which water supply is being planned.

- This quantity will thus vary with the number and types of industries present in the city
- In industrial cities, the per capita water requirement may finally be computed to be as high as 450 l/h/d as compared to the normal industrial requirement of 50 l/h/d.

WATER DEMAND OF CERTAIN IMPORTANT INDUSTRIES (AS PER GOI MANUAL)

| Name of Industry | Unit of Production | Approximate quantity of water required per unit of production |
|-----------------------|----------------------|---|
| 1. Automobile | Vehicle | 40 |
| 2. Fertilizers | Tonne | 80 - 200 |
| 3. Leather | Tonne (or 100 kg) | 40 4 |
| 4. Paper | Tonne | 200 - 400 |
| 5. Petroleum Refinery | Tonne (crude) | 1 - 2 |
| 6. Sugar | Tonne (cane crushed) | 1 - 2 |

C) Demand for Public Uses:

This includes water requirement for parks, gardening, washing of roads, etc. A nominal amount not exceeding 5% of the total consumption may be provided to meet this demand.

D) Fire Demand:

The quantity of water required for extinguishing fire is not very large. For a total amount of water consumption for a city of 50 lakhs population hardly amounts to 1 lpcd of fire demand. But this water should be easily available and kept always stored in storage reservoirs.

Following requirements must be met for the fire demand.

- Three jet streams are simultaneously thrown from each hydrant; one on the burning property, and one each on

either sides of the burning property. The discharge of each stream should be about 1100 l/min.

- The minimum water pressure available at fire hydrants should be of the order of 100 to 150 KN/m² (10 to 15 m of water head) and should be maintained even after 4 to 5 hours of constant use of fire hydrant.
- For cities having population exceeding 50,000, the water required in **kilo liters** may be computed by the formula of $100\sqrt{P}$, where P = population in thousands.
- Some other formulas (Kuichling's, freeman, National Board of fire Under Writers, Boston's Formula) are also used.

1) Kuichling's Formula

$$Q = 3182\sqrt{P} \text{ l/min.}$$

Where, P = population in thousands

2) National Board of Fire Under Writers Formula

(a) For a central congested high valued city.

- (i) When population is < or = 2 lakhs
- $$Q = 4,637\sqrt{P} \left[1 - 0.01\sqrt{P} \right] \text{ l/min.}$$

Where P is in thousands

- (ii) When population is > 2 lakhs, a provision for 54600 l/min. may be made with an extra additional provision of 9,100 to 36,400 l/min. for second fire.

Example 5

Compute the 'fire demand' for a city of 2 lack population by any formulae (including that of the National Board of Fire Underwriters).

Solution

- (i) The rate of fire demand as per National Board of fire Under Writers Formula for a central congested city whose population is < or = 2 lakhs is given by

$$Q = 4637\sqrt{P} \left[1 - 0.01\sqrt{P} \right]$$

$$Q = 4637\sqrt{200} \left[1 - 0.01\sqrt{200} \right]$$

$$Q = 56303.08 \text{ l/min.}$$

$$= \frac{56303.08 \times 60 \times 24}{10^6} \text{ MLD}$$

$$= 81.08 \text{ MLD}$$

(ii) Kuichling's formula

$$Q = 3182\sqrt{P} = 3182\sqrt{200} \text{ l/min.}$$

$$Q = 45000.27 \text{ l/min.} = 64.8 \text{ MLD}$$

- **Water Demand For Losses and Theft**
This includes the water lost in leakage due to bad plumbing, stolen water due to bad plumbing, stolen water due to unauthorized water connections, and other losses and wastes.
- This amount may be as high as 15% of the total demand.

1.5 THE PER CAPITA DEMAND (q)

This is the annual average amount of daily water required by one person, and includes the domestic use, industrial and commercial use, public use, wastes, thefts etc.

Per capita Demand (q) in litres per day per head

= Total yearly water requirement of the city in liters / (365 × Design of population)

1.6 FACTORS AFFECTING PER CAPITA DEMAND

(i) **Size of the City:** Demand increases with the size of the city.

- On an average, the per capita demand for Indian towns may vary with the population as shown below

| Population | Per capita Demand (lpcd) |
|---------------------|--------------------------|
| < 2000 | 110 |
| 20 to 50 thousands | 110 - 150 |
| 50 to 200 thousands | 150 - 240 |
| 2 lakhs to 5 lakhs | 240 - 275 |
| 5 lakhs to 10 lakhs | 275 - 335 |
| > 10 lakhs | 335 - 360 |

- The above figures are liable to variation up to above 25%.
- For Indian condition, I.S. Code permits maximum value of 335 lpcd.

(ii) **Climatic condition**

(iii) **Type of Gentry and habit of people.**

- Rich and Upper class communities generally consume more water due to their affluent living standards

(iv) **Industrial and commercial activities**

(v) **Quality of water supply**

(vi) **Deopment of Sewerage facilities**

(vii) **Cost of water and method charging**

(viii) **Pressure in the distribution system**

Higher pressure in the distribution pipes ensure more water consumption

(ix) **System of supply**

- The water may be supplied either continuously or intermittently.
- The intermittent supplies, may lead to some saving in water consumption due to losses occurring for lesser time.

1.7 VARIATION IN DEMAND AND THEIR EFFECTS ON THE DESIGN OF VARIOUS COMPONENT OF A WATER SUPPLY SCHEME

- The smaller the town, the more variable is the demand. The shorter the period of draft, the greater is departure from the mean.
- The maximum demands (monthly , daily or hourly) are generally expressed as ratios of their means.

(i) **Maximum Daily Consumption**

Maximum daily consumption = 1.8 × Avg. daily consumption = 1.8 × q

(ii) **Maximum hourly Consumption**

Maximum hourly consumption of the maximum day i.e., Peak demand = 1.5 × Avg hourly consumption of the maximum = 1.5 × day

$$\left[1.8 \times \frac{q}{24} \right] = 2.7 \left[\frac{q}{24} \right]$$

iii) **Maximum Weekly Demand**

Maximum weekly consumption = 1.48 × Avg weekly

iv) **Maximum Monthly Demand**

Maximum monthly consumption = $1.28 \times \text{Avg monthly}$

- Good-rich formula to find peak demand to an average demand ratio

$$P = 180 \times t^{-0.1}$$

Where P = percent of the annual average draft for the time 't' in days.

1.8 PEAK FACTOR

- The per capita rate of water supply indicates only the average consumption of water per day per person over a period of one year, however this season, months, day and hour.
- The fluctuation in consumption is accounted for, by considering the peak rate of consumption which is equal to average rate multiplied by a peak factor.
- The following peak factors are recommended for various population are
 - i) Up to 50,0003
 - ii) 50,001 – 2,00,000.....2.5
 - iii) Above 2 lakhs.....2
 - iv) For small water supply scheme.....3

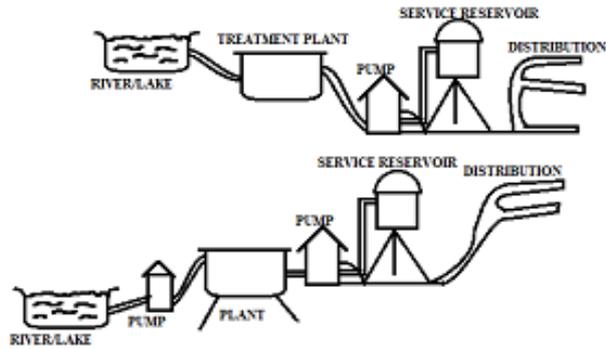
Note: As for as the design of distribution system is concerned, it is the hourly variation in consumption that matter.

1.9 COINCIDENT DRAFT

For general community purpose, the total draft is not taken as the sum of maximum hourly demand and fire-demand, but is taken as sum of maximum daily demand and fire demand or the maximum hourly demand, which every is more. The maximum daily demand (i.e., $1.8 \times$ average daily demand) when added to the fire demand is known as the **coincident draft**.

1.10 DESIGN CAPACITY OF VARIOUS COMPONENTS OF WATER SUPPLY SCHEME

The various components of water supply scheme as shown in figure below



The following recommendations may be adopted for designing the capacities of different components, of a water supply scheme.

1. The sources of supply (such as wells) may be designed for maximum daily consumption or sometimes for average daily consumption.
2. The pipe mains (to take from source to service reservoir), filter and other treatment unit are designed for maximum daily draft.
3. The pumps may be design for maximum daily draft plus some additional reserve for break down and repair.
4. The distribution system (to carry water from service reservoir to water tamps) should be designed for maximum hourly draft of maximum day or coincident draft with fire, whichever is more.
5. The service reservoir is designed to take care of hourly fluctuations; fire demands and emergency reserves.

2

QUALITY PARAMETERS OF WATER

QUALITY PARAMETERS OF WATER

Water impurities are classified as physical, chemical and biological impurities

2.1 PHYSICAL WATER QUALITY PARAMETER

- Suspended solids,
- Turbidity,
- Colour,
- Taste and odour,
- Temperature

2.1.1 SUSPENDED SOLIDS

Source:

These are called as physical parameters whereas dissolved solids are considered as chemical parameters. Suspended solids comes from inorganic particles like silt, clay etc., Immiscible liquids like oils and greases and organic particles like plant fiber, algae, etc. Inorganic solids are non-degradable solids.

Note: Problem of SS comes only in surface water not in ground water.

Objection:

These are objectionable because

- (a) Aesthetically displeasing.
- (b) It provides adsorption sites for chemical and biological agents
- (c) They may also be biologically active and may form disease causing organisms as well as organisms such as toxin producing strains of algae.

Measurement

- Most of the methods are gravimetric i.e. SS are calculated by weighing them.
- Total solids i.e. all solids (suspended or dissolved) are calculated by evaporating the sample and measuring

the residue. Heating temperature is 104°C.

- Suspended solid is obtained by filtration and heating the residue on filter at 104°C

Dissolved solids (DS) = Total solids (TS) – Suspended solids(SS)

Note: Filtration in real terms does not exactly divides the solids into suspended and dissolved fractions because some colloids may pass through the filter and can get measured along with dissolved fraction. Hence, classification is does as filterable solids. Hence suspended solids are corresponding to non – filterable solids and dissolved solids are corresponding to filterable solids.

- The organic content of both total and dissolved solid can be determined by firing the residue at 600°C.

Organic fraction ^{600°C} CO₂ + Water + Other gases

The Permissible limits

For suspended solid as per EPA (Environmental Protection Agency) is 30 mg/l

2.1.2 TURBIDITY

Source:

Turbidity is the measure of extent to which light is either absorbed or scattered by suspended material in water. It is not a direct quantitative measure of suspended solids.

Objection:

- Disinfection of turbid water is difficult because the suspended solids may partially shield the organisms from disinfectant.

- In natural bodies, turbidity interferes with light penetration and hence with the photosynthetic reactions (which gives oxygen to the water).

Measurement

Measurement of turbidity is done using the following:

- Turbidity rod
- Jackson's turbid meter
- Baylis turbid meter
- Nephelometer

Turbidity rod

- Rod with platinum needle is inserted water and the depth at which platinum needle just becomes invisible gives turbidity in ppm.
- As depth of insertion increases, reading will decrease.
- Turbidity which one milligram of finely divided silica produces in one liter of distilled water is taken as one unit.
- The permissible limit is 5 – 10 ppm.
- It is a field method.

Note:GOI manual gives turbidity in NTU i.e. Nephelometer turbidity unit. Acc

Jackson's Turbid meter

- The level of water is increased till the image of flame ceases to be seen.
- The turbidity is measured from graduated glass tube.
- It is used when turbidity is greater than 25 ppm.
- It is a laboratory method.
- This method is not used for drinking water.

Note:Turbid raw water of natural source has turbidity greater than 25 ppm.

Baylis Turbid meter and Nephelometer

- Baylis and Nephelometer turbid meters are based on colour matching techniques.
- In this case even a small turbidity of one unit or less can be measured.

- Hence these are most widely used for domestic water supplies.
- In Baylis turbiditymeter light intensity is measured in the direction of incident light only where as in Nephelometer light intensity is measured as right angles to the incident ray.
- Hence NTU is based in **Scattering principle**.
- If Formazine, a chemical, is used as base in place of SiO₂. The turbidity is also sometimes called FTU.

2.1.3 COLOUR

Source

Colour is caused by suspended and dissolved matter in water.

- After suspended matter causing colour is removed by centrifugation, the colour obtained is called true colour.
- Humic acid gives yellowish brown colour, Iron oxide gives reddish colour, manganese oxide gives brown or blackish water.
- Water containing oxidized iron and manganese impart characteristic reddish or black colour. Heavy growth of algae may also impart colour to the water.

Objection

- Coloured water is not suitable for dyeing purpose.
- Organic compounds causing colour may exert chlorine demand and hence reduces the effectiveness of disinfection by chlorine.
- Phenolic compound with chlorine produces taste and odour.
- Some colour causing organic compounds with chlorine becomes carcinogenic.

Measurement

- Measurement of colour is done by colour matching technique (tintometer).

- Result is expressed in TCU or Hazen unit (True colour unit) where 1 TCU is equal to color produced by 1 mg per litre of platinum in the form of chloroplatination (It is only for yellowish brown color)
 - For colour other than yellowish brown i.e. from industrial effluent, spectro photometric technique is used.
 - The colour testing is done within 72 hours of collection as otherwise biological or physical properties may change.
- Permissible limit:** Acceptable limit is 5 TCU and cause for rejection is 25 TCU.

2.1.4 TASTE AND ODOUR

- Taste and odour are caused by dissolve gasses like H₂S (Hydrogen sulphide), mercaptans, methan, organic matter derived from certain dead or living microorganism, decomposing organic matter, industrial liquid, waters containing phenols , cresols , ammonia , agricultural chemicals, high residual chlorine and chloro-phenols.

Source

- Sulphur imparts rotten egg like taste and odour.
- Algae secretes oily substances that may result in bad taste and odour.

Objection: The taste and odour causing compounds may be carcinogenic.

Measurement

- Measurement of taste and odour causing organics can be done using gas or liquid chromatography. However this method is costly and not done in routine.
- Odour is generally measured by an instrument known as **somoscope**.
- Intensity of taste and odour is measured by **Threshold odour number. (TON)**

- It represents the dilution ratio at which odour is hardly detectable.
- TON allowed is between 1 – 3.
- TON testing is done in cold water because increase in temperature may change the taste and odour.
- The formula for $TON = \frac{A+B}{A}$ where A is the volume of odours water in mL and B is the volume of odour free water required to procedure a mixture in which odour is hardly detectable.
- Odour can be removed by mechanical aeration, oxidation by chemicals like chlorine or its compounds or ozone or permanganate and adsorption of odour by agents such as activated carbon. Floc or clays.

Temperature

- Temperature affects the chemical and biological reactions. An increase in 10°C , doubles the biological activity. Hence for water supply, the temperature should be between 10-25°C and greater than 25°C is objectional.

2.2 CHEMICAL PROPERTIES OF WATER

- Total Dissolved Solids(TDS)
- Alkalinity
- pH
- Hardness
- Chloride Content
- Nitrogen Content
- Phosphorus
- Fluorides
- Metals

2.2.1 TOTAL DISSOLVED SOLIDS (TDS)

- The material remaining in the water after filtration is considered to be dissolved.
- A direct measurement of TDS can be made by evaporating to dryness a sample of water which has been filtered (to remove the suspended solids). The

residual is weighed and represents the TDS in the water.

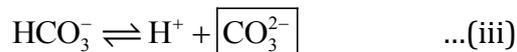
- Approximate analysis of TDS is often made by determining the electrical conductivity of water. (Electrical conductivity in $\mu\text{Mho/cm}$ at 25°C) $\times 0.65 =$ dissolved solid content in mg/l .
- Electrical conductivity is measured by di-ionic water tester. Ions usually for vast majority of TDS.
- Source of Total dissolved solids Major source Na, Ca, Mg, HCO_3^- , SO_4^{2-} Cl- Minor source Fe, K, CO_3^{2-} , NO_3^- , Fluoride Boron, Silica
- Major list characterizes the dissolved solid content of water and these are called common ions.
- According to GOI manual, acceptable limits of TDS (mg/l) is 500 and cause rejection is 2000.

Note: The ability of a water to conduct electricity, known as the specific conductance. Unfortunately, specific conductance and concentration of TDS are not related on a one-to-one basis. Only ionized substances contribute to specific conductance. Organic molecules and compounds that dissolve without ionizing are not measured.

2.2.2 ALKALINITY

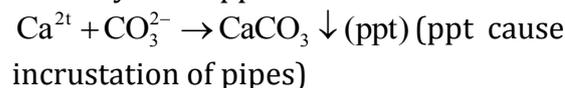
- Alkalinity is defined as quantity of ions in water that will react to neutralize hydrogen ions (H^+). Alkalinity is thus a measure of the ability of water to neutralize acids.
- Most common constituents of alkalinity are CO_3^{2-} , HCO_3^- , OH^- .
- Alkalinity caused CO_3^{2-} is called carbonate alkalinity, Alkalinity caused by HCO_3^- is called bicarbonate alkalinity and alkalinity caused by OH^- is called caustic alkalinity.
- The other minor sources of alkalinity are HSiO_3^- , H_2BO_3^- , HPO_4^-
- Alkalinity in water comes due to minerals or it may be produced to atmospheric CO_2 mixed in water or due

to microbial decomposition of organic matter. The reaction are as follows:



The last reaction (iv) is a weak reaction but utilization of HCO_3^- by algae in water drives the reaction to the right and hence sufficient accumulation of OH^- occurs i.e. If algae is present in water, the water becomes alkaline ($\text{pH} = 9$ to 10). The above reactions are due to microbial decomposition of organic matter. In addition to this alkalinity may be of mineral origin.

- Alkalinity imparts bitter taste to water. The principal objection is that reaction can occur between alkalinity and certain caustics in water. The resultant precipitate can foul pipes and other water system appurtenances.



2.2.3 pH

- $\text{pH} = -\log_{10} [\text{H}^+]$ where $[\text{H}^+]$ in moles / liter
- pH is measured by potentiometer in which potential exerted by H^+ is measured. Permissible value of pH in water
7 – 8.5 is acceptable limit
< 6.5 and > 9.2 is cause for rejection. It can also be measured by colour indicators. Colour formed is compared with standard colour.
- Indicators used are methyl orange. Its original colour is red and colour produced is yellow. pH range is **2.8 – 4.4**. **Methyl orange** is an acidic indicator.
- Phenolphthalein red has pH range of **8.6 – 10.3** original colour is yellow and

final colour is red. Phenolphthalein is a basic indicator.

- Acidic water causes corrosion and alkaline water causes incrustation of pipe.
- Alkaline water causes difficulty in chlorination. (Chlorine is a disinfectant.)

2.2.4 HARDNESS

- It is defined as concentration of multivalent metallic cations in solution. Multivalent metallic ions most abundant in natural water are Calcium & Magnesium. Other ions which leads to hardness are Fe^{2+} , Mn^{2+} , Strontium (Sr^{2+}) and Aluminium (Al^{3+}). But Fe^{2+} , Mn^{2+} , Sr^{2+} & Al^{3+} are found in much smaller quantities and hence for all practical purposes hardness may be represented by the sum of Ca^{2+} and Mg^{2+} ions.
- Hardness can be divided in two parts i.e. carbonate hardness and non-carbonate hardness.
- It is measured by using spectrophotometric techniques.
- HCO_3^- and CO_3^{2-} of calcium and magnesium cause carbonate hardness. It is also called temporary hardness because this hardness can be removed by simple boiling of water in which calcium carbonate precipitates.
Note: Magnesium carbonate is soluble in water, hence it does not precipitate.
- Sulphate, chloride and nitrate of calcium & magnesium gives permanent hardness. It is also called non-carbonate hardness. This hardness cannot be removed by simple boiling. It requires softening techniques.
- Hard water leads to lesser foam formation, hence consumption of soap would be more. It leads to scaling of boilers. It causes corrosion and incrustation of pipes. It makes food tasteless.
- Calcium hardness however does not cause any health problem.

- Hardness is expressed as $CaCO_3$ equivalent of Ca^{2+} and Mg^{2+} present in water in mg/litre.
- Amount of Ca^{2+} and Mg^{2+} in water is determined by titration with versenate solution (EDTA method). In EDTA method water is titrated with ethylene diamine tetra-acetic acid using **Eriochrome Black T (EBT)** as an indicator. EBT forms **red** colour and titration changes the colour to blue.
- If 0.01 M EDTA is used, 1 ml of the titrant is equivalent to 1 mg of hardness as $CaCO_3$.
- If $[Ca^{2+}]$ and $[Mg^{2+}]$ is known in mg/litre, total hardness would be equal to

$$\begin{aligned} \text{Total Hardness} &= \frac{[Mg^{2+}] \text{ mg/l}}{\text{eq. wt of mg}} \times \text{eq. wt of } CaCO_3 \\ &+ \frac{[Ca^{2+}] \text{ mg/l}}{\text{eq. wt of Ca}} \times \text{eq. wt of } CaCO_3 \\ \therefore \text{Total Hardness} &= [Ca^{2+}] \times \frac{50}{20} + [Mg^{2+}] \times \frac{50}{12} \end{aligned}$$

2.2.5 CHLORIDE CONTENT

- Chloride in water are derived mostly from natural mineral deposit, agricultural or irrigation discharges.
- Presence of chloride in high quantity indicates pollution of water due to sewage or industrial water.
- Chlorides are estimated by Mohr's method in which raw water is titrated with standard $AgNO_3$ solution using K_2CrO_4 (Potassium chromate) as indicator.
- Argentometric method is also used to detect chloride content.
- Acceptable limit is 200 mg/l and cause for rejection is 1000 mg/l.

2.2.6 NITROGEN CONTENT

- Presence of nitrogen in water indicates presence of organic matter.

- It occurs in the form of –
 - (a) Free ammonia → indicates recent pollution
 - (b) Organic ammonia (Albuminoid) → indicates quantity of nitrogen before decomposition has started.
 - (c) Nitrite → indicates partly decomposed condition
 - (d) Nitrate → indicates old pollution (fully oxidized)
- Free ammonia should not be more than 0.15 mg/l and it can be measured by simply boiling the water and measuring the liberated ammonia by distillation process.
- Organic ammonia should not be more than 0.3 mg/l and it is measured by boiling a sample of already boiled water plus strong alkaline solution like KMnO_4 and measuring the ammonia so liberated.
- Free ammonia + organic ammonia = **Kjedahl Nitrogen Ammonia**
- Nitrite is highly dangerous, hence its permissible limit is zero. It is measured by colour matching technique. The colour for nitrite is developed by sulphonic acid + Napthamine
- Nitrate is not harmful as it is fully oxidized. But too much nitrate affects infants. Because it caused **blue baby disease** or **Mathemoglobinemia** Nitrate concentration should not be more than 45 mg/l. Its concentration is measured by colour matching technique. Colour is formed by phenol-disulphonic acid + Potassium Hydroxide.

2.2.7 PHOSPHORUS

- It is not toxic and do not represent direct health threat. But is indirect threat to water quality because.
 - (a) It facilitates rapid growth of aquatic plants.
 - (b) It interfaces with water treatment like chemical coagulation.

- Even a low concentration of 0.2 mg/l interferes with the water treatment process.

2.2.8 FLUORIDES

- Up to 1 mg/l, it helps to prevent dental cavities. During formation of permanent teeth it combines chemically with tooth enamel, resulting in harder, stronger teeth that are more resistant to decay.
- Excess value (greater than 1.5 to 2 ppm) results in discoloration of teeth called mottling of teeth. (Infants are affected not adults).
- Greater than 5 mg/l causes deformation of bones called bone fluorosis.
- Excessive dosages of fluoride can also result in bone fluorosis and other skeleton abnormalities.
- Acceptable limit is upto 1 mg/l and greater than 1.5 mg/l is cause for rejection

2.2.9 METALS

- Metals are of two types i.e., toxic and non-toxic.
- Ca, K, Na, Fe, Mn, Zn are non-toxic metals.
- Arsenic, Barium, Cadmium, Chromium, Cyanide, Lead & Mercury are toxic metals.

i) Sodium

- Excess Na (sodium) concentration causes bad taste and harmful for cardiac and kidney patients. It is also corrosive to metal surface and in large concentration, it is toxic for plants.
- **Measurements:** Atomic absorption spectrophotometry.

ii) Iron and Manganese

- Some bacteria use iron and manganese compounds for an energy source and resulting slime

growth may produce taste and odour.

- $\text{Fe}(\text{HCO}_3)_2 \xrightarrow{\text{O}_1} \text{Fe}(\text{OH})_3 \downarrow$
(Similarly manganese also precipitates.)
 $\text{FeCl}_3 \xrightarrow{\text{O}_2} \text{Fe}(\text{OH})_3 \downarrow$
 $\text{FeSO}_4 \xrightarrow{\text{O}_2} \text{Fe}(\text{OH})_3 \downarrow$
- Iron and Manganese poses problems in ground water and bottom layers of lakes but not in surface water. Because surface water has sufficient O_2 and hence ppt of $\text{Fe}(\text{OH})_2$ and MnO_2 will occur.
- Acceptable limit for Iron is 0.1 – 1.0 mg/l and for Mn 0.05 – 0.5 mg/l.

iii) Copper

- Its large quantity affects lungs and respiratory organs.
- Its limit is 0.05 – 1.5 mg / l.
- CuSO_4 greater than 250 mg / l Has laxative effect.

iv) Calcium (as Ca)

- Acceptable limit is 75 and cause for rejection is 200 mg / l.
- Essential for bones and teeth formation.

v) Sulphate (as SO_4)

- Acceptable limit is 200 and cause for rejection is 400 mg / l (**vi) Zinc (as Zn)**)
- Essential nutrient for life.
- Acceptable limit 5 and cause for rejection 15 mg / l.

vi) Arsenic

- Acute or chronic toxicity to humans
- Acceptable limit 0.01 and cause for rejection is 0.05 mg/l.

vii) Cadmium

- Cumulative. Highly toxic in humans and livestock.
- Affect all life.

- Its concentration must not be greater than 0.01 mg / l.

viii) Chromium (as hexavalent Cr)

- Toxic to human and plants
- It should not be greater than 0.05 mg/l.

ix) Cyanide (CN)

- Cyanides renders tissues incapable of oxygen exchange.
- It should not be greater than 0.02 mg/l.

x) Lead (Pb)

- Is toxic to many organs and tissues including the heart, bones, kidney intestines and reproductive and nervous systems.
- It should not be greater than 0.05 mg/l.

xi) Mercury

- Toxic to all form of life.
- Mercury Poisoning causes depression, numbness sensations, leaky gut syndrome, immune dysfunction etc.
- It should not be greater than 0.001 mg/l.

2.2.10 DISSOLVED GAS

- CH_4 which is studied for its explosive tendency.
- H_2S imparts bad taste and odour.
- CO_2 indicates biological activity, imparts bad taste and water becomes corrosive
- Oxygen level less than saturation level indicates oxygen deficiency.
 - To determine oxygen deficiency of water 10% solution of KMnO_4 is exposed to 27°C for 4 hours and the amount of oxygen absorbed is calculated.

2.2.11 ORGANICS

- These are classified as biodegradable and non-biodegradable organic.

2.2.12 BIODEGRADABLE

- Biodegradable organic are utilized for food by naturally occurring microorganisms examples of biodegradable organics are starch, fats, proteins, aldehydes and esters. **Microbial** utilization of disclosed organic is accompanied by:
 - (a) Oxidation
 - (b) Reduction
- Reaction in the presence of oxygen is called **aerobic reaction** and reaction in the absence of oxygen is called **anaerobic reaction**.
- Aerobic reaction gives stable end products whereas end product of anaerobic reaction is unstable.
- Amount of oxygen consumed during microbial utilization of organics is called **BOD** (biochemical oxygen demand).
- **BOD** after 5 days at 20°C is taken as standard **BOD**.
- $BOD_5 = \frac{[\text{initial Dissolved oxygen} - \text{Final Dissolved oxygen}] \times \text{Dilution factor}}{\text{Sample volume}}$
Where, Dilution factor = $\frac{\text{Final volume}}{\text{Sample volume}}$

Note: sample + pure water is diluted upto 300 ml and initial DO is noted in the diluted sample. The diluted sample is incubated at 20°C for 5 days and final DO is noted. Thus BOD₅ is calculated.

Note: In BOD taste all sources of light are removed otherwise if algae is present, algal growth will take place and in that process oxygen will be released in water. BOD of treated water should be zero.

2.2.13 NON-BIODEGRADABLE

- Examples of non-biodegradable organic are tannic acid, lignic acid, cellulose and phenols.
- They are constituents of woody plants.

- These organic decomposes slowly that they are called non-biodegradable. Besides these molecules with strong bonds are non-biodegradable like benzene, detergent compounds organic pesticides, industrial chemicals. Hydrocarbon combined with chlorine is toxic to organisms hence considered non-biodegradable.
- Measurement of non-biodegradable organic is done by COD i.e. chemical oxygen demand and also TOC i.e. total organic carbon.
- Both COD and TOC also measures biodegradable organic. COD is determined by mixing the sample with very strong oxidizing agent like $K_2Cr_2O_7$, which oxidizes all organic matter.
- Non-biodegradable organics
 $= \text{COD} - \text{BOD}_u$
 $\text{BOD}_u = \text{ultimate BOD}$

2.3 BACTERIAL AND MICROSCOPIC CHARACTERISTIC

- Aerobic Bacteria → Required oxygen for survival
 - Anaerobic Bacteria → Do not required dissolve O₂
 - Facultative Bacteria → can survive with or without O₂
- Through some species of bacteria may be helpful in cleaning of water but other pathogenic bacteria are harmful.
 - The presence of pathogenic bacteria can be tasted by counting presence of coil forms.

2.3.1 COLI FORMS (ALSO CALLED B COLI)

- Coliforms are important harmless aerobic microorganism which are found residing in the intestines of all warm blooded animals including human being.
- Since these harmless organism live longer in water than the pathogenic

bacteria it is generally presumed that the water will be safe are free from pathogens if no Coliform bacteria are present in it.

2.3.2 MEASUREMENT OF COLIFORM

- Widely used
- Filter the water through a sterile membrane of special design porosity = 80 pore size (5 to 10 μ m) and the membrane is put in contact with nutrients (m – Endo’s medium) that will permit the growth of only coliform colonies. This process is called culturing.
- After an incubation period of 20 hrs, the Coliform organs are developed into visible colonies which can be easily counted E.coli ferment lactose with gas formation with 48 hours incubation at 35°C. Based on this E.coli density is estimated by multiple fermentation procedure in different test. Which consist of identification of E.coli in different dilution combinations.
- MPN value is calculation as follows Five 10 ml (five dilution combinations) tube is tasted for E.coli and if out 5 only one give positive test for E.coli and all other are negative.
- The from the table we can find out the MNP value for one (+ve) and other (-ve), which is equal to 2.2 in present case

2.3.3 COLIFORM

Used to measure the Coliform bacteria present in water sample
 “It may be defined as the reciprocal of the smallest quantity of a sample which would give a positive B.coli test”

2.3.4 WATER BORNE DISEASES AND THEIR CONTROL

- a) Disease caused by Bacterial infections
 Disease caused by
 - i) Typhoid fever – salmonella typhi

- ii) Cholera – vibro – cholera
 - iii) Bacillary Dysentery – shiga bacillus or Flexner – bacillus
- b) Disease cause by viral infections
 - i) Hepatitis – Hepatist viral
 - ii) Poliomyelitis – polio virus
 - c) Disease caused by protozoal infections
 - i) Amoebic Dysentry – Antoneoba histolitic germ

2.3.5 QUALITY STANDARD FOR INDUSTRIAL WATER SUPPLY

Boiled ferrd water
 Hardness 1 mg/L
 Pulp and paper: L water should be free from iron Mn and hardness.

2.3.6 QUALITY STANDARD FOR MUNICIPAL WATER SUPPLY

Municipal water required for domestic uses, particularly the water required for drinking, must be colorless odourless and tasteless. It should be free turbidity and excessive toxic chemical & bacteriological characteristics of water must be in between the desirable & permissible limit. Basic Unit Process and Operation for Water Treatment.

| Unit Process | Function (Removal) colour, Odour taste |
|------------------|--|
| Screening | Floating matter |
| Chemical methods | Iron, Manganese |
| Softening | Hardness |
| Sedimentation | Suspended matter |
| Coagulation | Suspended matter, a part of colloidal water and bacteria |
| Filtration | Remaining colloidal dissolved matter, bacteria |
| Disinfecting | Pathogenic bacteria, organic & reducing substances. |

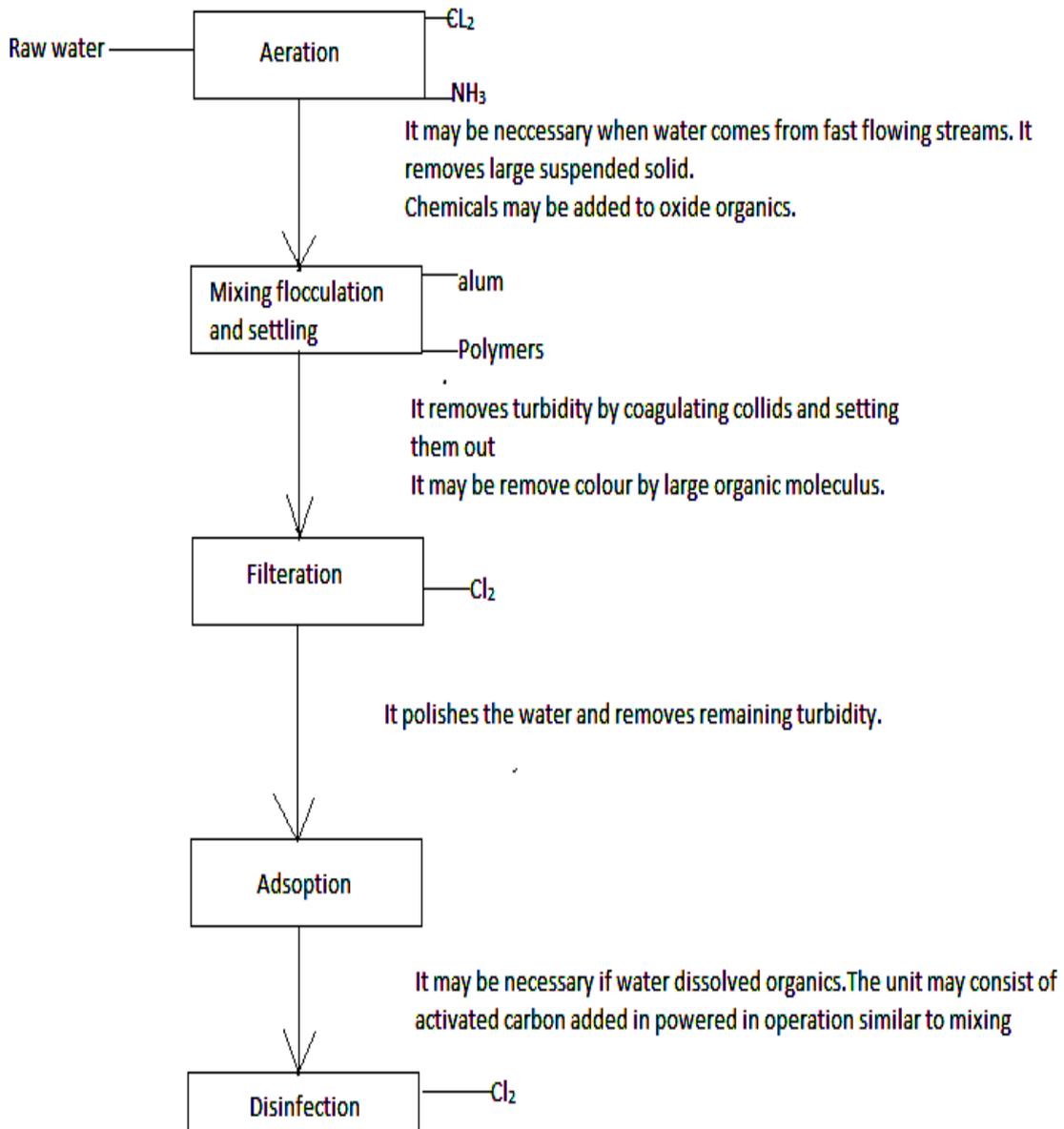
| Source | Treatment required |
|--|--|
| 1. Ground water and spring water fairly free from contamination | No treatment or chlorination |
| 2. Ground water with chemical, mineral and gases. | Aeration, coagulation (if necessary filtration and disinfection) |
| 3. Lakes, surface water, reservoir, with less amount of pollution. | Disinfection |
| 4. Other surface water such as river, canals and impounded reservoir with a considerable amount of pollution | Complete treatment |

3

TREATMENT OF WATER

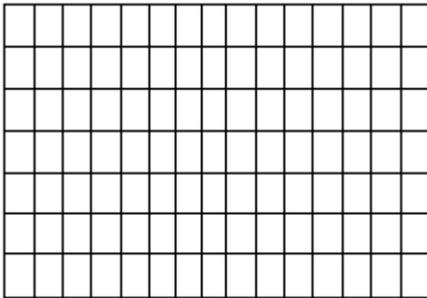
3.1 TREATMENT OF WATER

- Treatment plant treating turbid surface water with organics



3.1.1 SCREENING

- These are classified as **coarse screen** and **fine screen**.
- Coarse screens are in the form of bars spaced at **20 – 100 mm c/c**.
- It is kept inclined 3-6 V : 1 H for increasing flow area and to reduce velocity. Smaller velocity also helps in racking.
- Coarse screen is in the form of wire mesh with opening less than 10 m.m.



- As the fine screen gets clogged easily, head loss increases. Hence we try to avoid fine screens, fines particles may be settled in the sedimentation tank.

3.1.2 MICROS TRAINER

- It is useful for screening stored water, which do not contain a large amount of suspended matter, but contain plankton, algae and other small sized particles.
- They reduce the load on filter.
- Ideal position of micro-strainer (provided at intake to prevent floating material) is earlier to rapid gravity of slow sand filters whose efficiency is increased by approx 50%.

3.1.3 PRE-CHLORINATION

- Per-chlorination refers to practice of injecting chlorine into the raw water when it is not so turbid but has a high bacteria count.
- Fairly high dose of chlorine (2.5 mg/1) is used.

- During the lengthy period spent by water in the settling basins, this oxidizes and precipitates iron and manganese if present in water.
- Pre-chlorination also kills algae and bacteria,
- If excessive silt is present in suspension, pre-chlorine is not so effective because silt absorbs chlorine without settling. Hence, in case of heavily turbid water, it is not very effective.
- In case of clear ground water with high ammonia content, it is effective.
- A drawback of using pre-chlorination is that raw water has a high chlorine demand and more quantity of chlorine is absorbed than in later chlorination, to effect the same degree of sterilization. It is not a substitute for post chlorination. It is most advantageous when extremely polluted clear raw water has to be used.

3.2 AERATION

- Water is brought in intimate contact with air.
- It is used to remove undesirable gases dissolved in water like CO₂, H₂S.
- It is also used to add oxygen for oxidation of undesirable substances like oils, decomposing product of algae, etc.
- It is more often used for ground water as surface water is already in contact with atmosphere.
- It can also remove volatile liquids like phenols and humic acids but the rate is very slow. Hence aeration is adopted only when high concentrations are present.
- It removes iron and manganese. Iron and manganese are soluble in Fe²⁺ and Mn²⁺ form. They are oxidized to Fe(OH)₃ and MnO₂ which precipitates.

$$4\text{Fe}^{2+} + \text{O}_2 + 10\text{H}_2\text{O} \rightarrow 4\text{Fe}(\text{OH})_3 \downarrow + 8\text{H}^+$$

$$2\text{Mn}^{2+} + \text{O}_2 + 2\text{H}_2\text{O} \rightarrow 2\text{MnO}_2 \downarrow + 4\text{H}^+$$

- This process increases the **acidity** of water.

3.3 SEDIMENTATION

- It is a natural process by which solids with higher density than the fluid in which they are suspended, settle under the action of gravity.
- The purpose of sedimentation tank is to remove suspended solids.
- Sedimentation is classified into two categories :
 - Plain sedimentation, and
 - Sedimentation with coagulation
- Sedimentation Tanks are classified as **Quiescent type** (fill and draw type) and **continuous type**.
- The quiescent type tank will have detention time = 24 hr and period of cleaning = 8.12 hr. min. 3 nos of tank are required in quiescent type. Tank will be designed for max daily flow max daily flow = 1.8 x av. Daily flow.
- Settling velocity will be calculated by Stoke's law unless and otherwise given.

$$V_s = \frac{(Y_s - Y_w)d^2}{18\mu} \dots \text{applicable for } Re$$

< 1 (Stoke's law)

- Although Stoke's law is applicable for discrete particle settling. We shall use it in our course as an approximate method for calculating V_s .

Continuous Flow Type

- Horizontal flow tank → Rectangular.
- Vertical flow tank → Circular

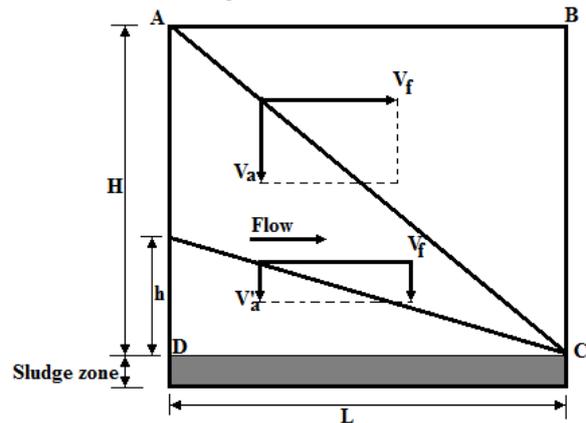
3.3.1 HORIZONTAL FLOW TANK

The design is based on the assumption that: concentration of suspended particle of suspended particle of each size is same at all points of the vertical cross-section at inlet end.

Assumptions ∫

A particle is removed when it reaches the

bottom of settling zone.



Time of horizontal flow

$$= \frac{\text{Length of tank}}{\text{Velocity of flow}} = \frac{L}{V_f}$$

$$\text{Velocity of flow, } V_f = \frac{Q}{BH}$$

Time of horizontal flow or (Detention time).

$$= \frac{L}{Q/BH} = \frac{LBH}{Q}$$

$$= \frac{\text{Volume of tank}}{\text{Discharge}}$$

$$\text{Time of falling through height (H)} = \frac{H}{V_s}$$

If a particle of settling velocity V_s is introduced at the top most inlet point, it will be assumed to be removed if time of falling through H is detention time.

$$\Rightarrow \frac{H}{V_s} = \frac{LBH}{Q} \Rightarrow V_s = \frac{Q}{BL}$$

- This quantity $V_s = \frac{Q}{BL}$ is called overflow rate.
- Hence surface overflow rate can be thought of as settling velocity of that particle which if introduced of the top most point at inlet will reach the bottom most point at outlet.
- This implies that particles having size greater than the particle for which settling velocity is equal to overflow rate, is 100% removed.

- Particle having settling velocity less than overflow rate will not get 100% removed.
- Percentage removal of these particles will be is given by $\left(\frac{h}{H}\right)$

$$\frac{h}{V_s} = \text{Detention time} = \frac{H}{\text{overflow rate}} = \frac{H}{V_s}$$

$$\Rightarrow \boxed{\frac{h}{H} = \frac{V_s}{V_s}}$$

Percentage removal of particle having settling velocity $V_s = \frac{V_s}{V_s} \times 100$

Note: If the overflow rate is increased, the efficiency of sedimentation tank is decreased and vice versa. Theoretically depth does not have any effect on the efficiency of tank.

3.3.2 SHORT CIRCUITING IN SEDIMENTATION TANK

As per the ideal condition each batch of water is supposed to remain in the tank for detention time i.e., the time to reach from inlet to outlet.

$$\text{Where Detention (T)} = \frac{V}{Q}$$

V = Volume of tank

Q = Rate of flow

- In actual working tanks, these ideal flow conditions do not exist due to currents induced by the inertia of incoming fluid, turbulent flow, wind stress, density and temperature gradient.
- The deviation of actual flow of tank from the flow pattern of ideal tank is called short-circuiting.
- In short-circuiting, top layers of water has detention time (t) which is far less than the detention time of bottom layer.
- Degree of short-circuiting is the derivation of actual flow pattern to the ideal flow pattern. Hence, Displacement efficiency

$$(n_d) = \frac{\text{Flow through period}}{\text{Theoretical Detention Time}} \times 100$$

- Generally $(n_d) > 30\%$

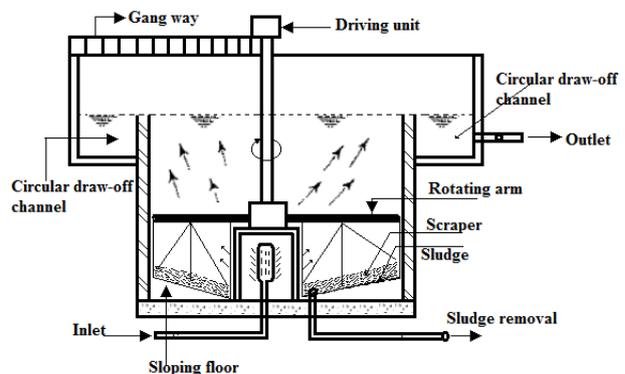
3.4 TUBE SETTLER

As we know that discrete particles settling efficiency of the sedimentation tank is primarily dependent upon the surface area of the tank and independent of its depth. Therefore, the sedimentation basin should be made as shallow as possible.

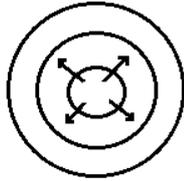
Attempts have, therefore, been made to place horizontal trays in the tank, to divide the tank height into compartments, to reduce the depth and to provide multiple surface area (i.e., increased surface area) thereby reducing the surface overflow rate and hence causing more particle settlement. But due to clogging and biological growth these arrangement are not used now a days.

However, very small diameter tubes having high wetted perimeter relative to wetted area, providing laminar flow conditions and low surface loading rate, have shown good clarification. Such tube setting devices called tube settlers, whose detention time is $< \text{or} = 10$ minutes.

3.4.1 CIRCULAR SEDIMENTATION TANK



In circular tank, horizontal flow velocity of water is continuously decreasing at the distance from centre increases. Hence particle path will be parabolic as opposite to straight line path in case of horizontal flow tank.



Volume of circular tank is given by

$$V = D^2(0.785H + 0.011D)$$

$$Q \times t_d = \text{volume}$$

$$\text{Over flow rate} = \frac{Q}{\frac{\pi d^2}{4}}$$

- Weir loading Rate = $\frac{Q}{\pi D}$ Basically weir loading rate affects lighter particle (flocs) clarification.
- Weir loading Rate is normally taken as 300 m³/d/m but when tank are property design its value goes up to 1500 m³/d/m

3.4.2 SEDIMENTATION WITH COAGULATION

- Efficiency of sedimentation tank is very low when water contains very fine suspended particles.
- Coarse solids are effectively removed by sedimentation process (as discussed earlier) as their size enable them to settle by gravity.
- Solids, which are not coarse, more so if they are not coarse, more so if they are colloidal than it pass along with the effluents of the setting basins.
- A colloidal dispersion is defined as stable when the dispersion show little or no tendency to aggregate.
- For settlement of colloidal particles aggregate is essential. The aggregation of colloidal particles requires:
 - (a) Particle destabilization to permit attachment when contact occurs, and
 - (b) Agglomeration of the destabilized particles.
- Coagulation is defined as the addition of a chemical to a colloidal dispersion which results in particle destabilization by the reduction in forces, which tend to keep particles apart.
- The added chemical is called the COAGULANT.
- Coagulation result in the reduction of surface charges and the formation of perceptible complex hydrous oxides.
- The process involve the agitated addition of the coagulant and the forming of either flocculent suspensions of compounds, which entrap undesired constituents and carry them out of solution or the formation of insoluble precipitates of the undesired constituents themselves.
- Examples of the former include organic suspended and colloidal matter and while the second include precipitates of phosphorus and heavy metals.
- Most microscopic and colloidal particles are stabilized by the formation of layers of ions, which tend to collect around the particle and form a protective barriers for stabilization.
- These ionic layers tend to act as part of the particle and travel with it through solution, inhibiting the close approach of respective particles to each other.
- Both the thickness of the ionic layers and the surface charge density are sensitive to the concentration and the valence of ions in solution.
- Hence, the stability of a suspension may be markedly affected of altered by adding suitable ions with large positive charges (e.g. aluminium and ferric salts) into the solution.
- The “Zeta potential” is a measure of the stability of particle and indicates the potential, which would be required to penetrate the layer of ions surrounding the particle for destabilization. Hence, the higher the zeta potential, the more stable the particle.
- The purpose of coagulation is to reduce the zeta potential by adding agglomerate.
- The suitable ions are usually provided by aluminium salts, lime and various polymers, which are common coagulants.

- Where floc formation is poor, coagulant aids are added.
- By producing a heavier, faster-settling floc, this allows smaller-basins to be used and smaller doses of the main coagulants may also be possible.
- The choice of the best coagulant for any particular water is determined by an experiment known as **Jar Test**, which will be described subsequently.

3.4.3 MECHANISM OF COAGULATION

- Ionic layer compression
- Adsorption and charge neutralization
- Sweep coagulation
- Inter-particle bridging

a) Ionic Layer Compression:

- The quantity of ions in water surrounding a colloid has an effect on reducing the repulsive force.
- A high ion concentration compresses the layers composed predominantly of (+ve) charge ions towards the surface of colloid. If this layer is sufficiently compressed then attractive forces (vander waal force) will be predominant. Thus the particles will collapse and will grow in size. Thus they will be removed in the sedimentation tank.

b) Adsorption & Charge Neutrallisation:

- Nature rather than quantity of ion is of prime importance in the theory of adsorption and charge neutralization. If Alum is added in water, it will form Al^{3+} and SO_4^{2-} . The sulphate ion (SO_4^{2-}) may remain in this form or may combined with other cations like Na^+ , Mg^{2+} . However Al^{3+} ion will react immediately with water to form various aquametallic cations like. $Al(OH)^{2+}$, $Al(OH_2)^+$, $Al_7(OH)_{17}^{4+}$, $Al(OH)_3 \downarrow H^+$.
- These cations surrounds the clouds of (-ve) charge and as they have an

affinity for surface, they are adsorbed on to the surface, thereby neutralizing the surface charge.

- Once the charge is neutralise, free contact can occur. Thus size increases and settling tanks place.

Note:Overdosing may lead to net (+ve) charge which will again result in suspension

c) Sweep Coagulation:

- The aluminum hydroxide ($Al(OH)_3$) formed when alum is added to water is a amorphous (shapeless) and gelatinous (sticky) ppt. These are heavier than water is settles down by gravity. Colloids may become entrapped in the flocs as the flocs settle down. This process by which colloids are swept away from the system in this manner is called sweep coagulation.

d) Inter Particle Bridging:

- Large molecules may be formed when Al or ferric sulphate dissociate in water (like $Al_7(OH)_{17}^{4+}$).
- Several colloids may become attached to one molecule or various molecules may get enmeshed resulting in settleable mass.
- Polymers may also be used either alone or in combination with alum or iron salts.

3.5 FILTRATION

- Filtration removes fine flow particles, colour, dissolved minerals and microorganisms.
- It also removes the suspended solids that does not get removed in sedimentation.
- It is economically effective in controlling guinea worm disease.
- Filters are classified as :

- (a) Slow sand filter
 - (b) Rapid sand filter
 - (c) Pressure filter
- } gravity filters

- In gravity filters the head required to flow through sand will be provided by the head of water over the sand medium but in pressure filtration, the necessary head would be provided by pressure applied from outside. Hence the pressure filter should be inside a closed container.
- Slow sand filter removes larger percentage of impurities as compared to rapid sand filters.
- Slow sand filters have very slow rate of filtration about $\frac{1}{30}$ th of the rapid sand filter.

3.5.1 THEORY OF FILTRATION

- a) Mechanical Straining
- b) Sedimentation
- c) Biological action
- d) Electrolytic changes

a) Mechanical Straining

Most of the particles are removed in upper layers. Arrested impurities including the coagulated flock forms a mat on top which further helps in straining.

b) Sedimentation

Particles finer than voids are removed by sedimentation. The particles stick to already settled gelatinous mass in the pores of filter medium.

c) Biological Metabolism

The sand bed has been identified as three zones of purification :

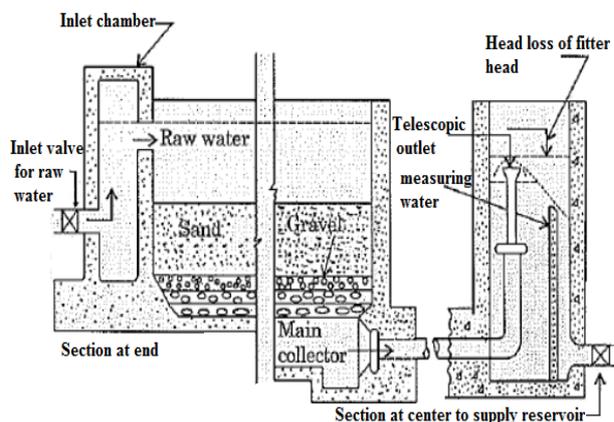
- The surface coating is known as “schmutzdecke”,
- The ‘autotropic’ zone existing a few millimeters below the zone ‘a’, and

- The “heterotrophic” zone, which extends around 300 mm into the bed.

d) Electrolytic Changes

- Sand grains in filter and impurities in water carry opposite charges. Thus because of their interaction, chemical characteristics of water changes and it becomes pure.
- During washing process of filter neutralized material is removed.

3.6 SLOW SAND FILTER



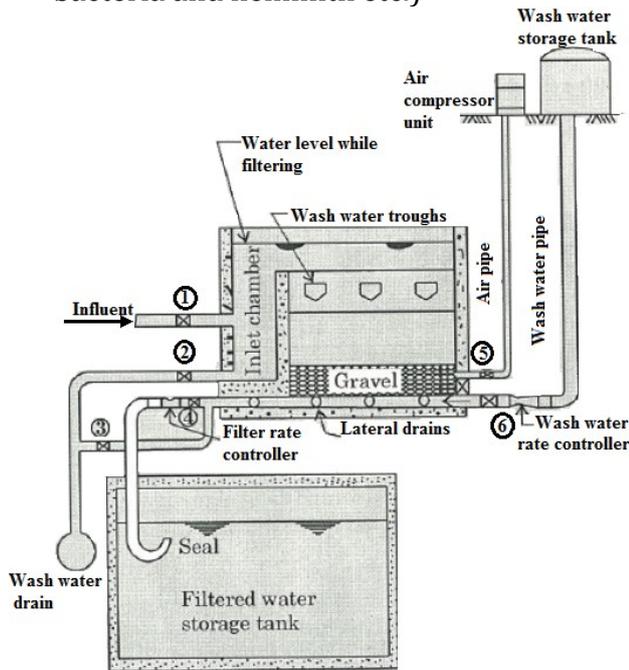
- It utilizes the effluent from plain sedimentation tank only. Which are relatively clearer.
- Depth of tank is 2.5 to 3.5 m.
- Plan area required is 100-2000 m^2 .
- Filter medium is sand or anthracite or garnet.
- D_{10} (of filter medium) = 0.2 – 0.3 mm.
- $\frac{D_{60}}{D_{10}}$ = uniformity coefficient = 5 (as per GOI manual).
- Depth of sand is 90 –110 cm \approx 1 m
- Depth of water over sand medium would be approximately the same as the depth of sand medium.
- Top 15 cm of sand layer would be finer remaining may be of uniform size.
- Because material is gravel provided in 3 layers.

Top layer size – 3 - 6 mm
 Middle layer – 20 - 40 mm
 Bottom layer – 40 - 65 mm

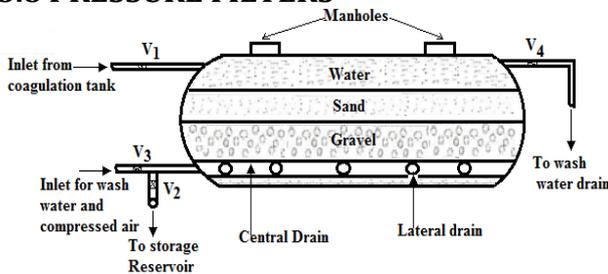
- Design period of slow sand filter is 10 years.

3.7 RAPID GRAVITY FILTER

- Particles more than and less than 1 μm diameter are efficiently removed.
- Removes suspended & colloidal matter
- It also removes microorganisms (i.e. bacteria and helminth etc.)



3.8 PRESSURE FILTERS



- The unit is like a rapid sand filter with a difference that complete unit is inside a closed chamber. Flow of water through sand is not under gravity. This implies that water inside the chamber is under pressure.
- Diameter of the tank is 1.5 – 3.0 m.
- Height or length is 3.5 to 8.0 m.

- It is operated like a rapid gravity filter except that raw water is neither flocculated nor sedimented before it enters the filter.
- It is used for clarifying softened water at industrial plants and in treating swimming pool water.

3.8.1 PRESSURE FILTER SUFFERS FROM THE FOLLOWING DISADVANTAGES

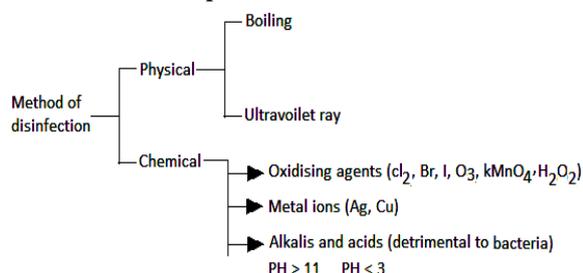
1. Treatment of water under pressure seriously complicates effective feeding mixing and flocculation of water to be filters.
2. In case of direct supply from pressure filter it is not possible to provide adequate contact time for chlorine.
3. Water under filtration and the sand bed are out of sight and it is not possible to observe the effectiveness of the backwash or the degree of agitation during wasting process.
4. It is difficult to inspect clean and replace the sand, gravel and under-drain of pressure filter and
5. Became the water is under pressure at the delivery end. On occasions, when the pressure on the discharge main is released suddenly the entire sand bed might be disturbed violently with disastrous results to the filter efficient.

3.9 DISINFECTION

- Disinfection may be defined as the process of destruction or inactivation of harmful micro-organism in water either by physical process or chemical process. Physical process includes heating, ultraviolet radiation etc. and chemical process includes addition of disinfectants such as chemicals.
- Disinfection can be distinguished from sterilization. In sterilization process, all organisms are usually killed by a physical phenomenon such as boiling for a long period whereas in disinfection disease or illness causing

micro-organism are reduced to such low level that no infection or disease results when the water is used for domestic purposes including drinking water.

- Disinfection is an essential minimum treatment requirement for any drinking water and it is the final process in the chain of water purification.



- Out of various methods chlorination is most commonly adopted.

3.9.1 MINOR METHODS

a) Treatment with excess lime

- Excess lime kills bacteria but excess lime (14 – 40 ppm) has to be removed before supply. For this recarbonation is done.
- It is not used now a days.

b) Treatment with ozone

- Nascent oxygen is a powerful oxidizing agent and it removes organic matter as well as bacteria from water.
- 2 – 3 ppm ozone is required to maintain a residual of 0.1 ppm.
- Residual ozone is measured by orthotolidine test.
- Ozone is unstable hence nothing remains in water by the time it reaches the distribution system.
- Ozone removes colour, taste and odour also.
- It gives pleasant test to water.
- It does not ensure safety against future recontamination.
- It is less efficient than chlorine in killing bacteria.

c) Treatment with F and Br

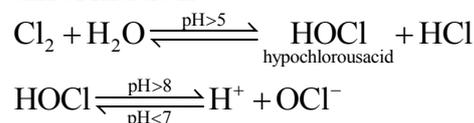
They are available in the form of pills.

d) Treatment with KMnO₄

- It is a popular disinfectant for well water supplied in villages which are contaminated with lesser amount of bacteria.
- Besides killing bacteria, it also helps in oxidizing the taste producing organic matter, hence it is sometimes added to even filtered and chlorinated water
- KMnO₄ is mixed with water in a bucket and added to well. Pink colour forms because of this. If pink colour disappears, this implies that organic matter is present
- Hence more KMnO₄ is added until the pink colour stands. The well is not used for next 48 hours.
- Does is normally 1 to 2 mg/lit and the contact period is 4 to 6 hrs.
- It removes 98% (approx) bacteria but removes 100% bacteria causing cholera.
- Water treated with KMnO₄ with passage of time produces dark brown precipitate.

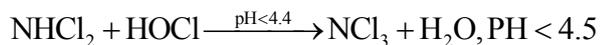
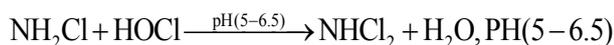
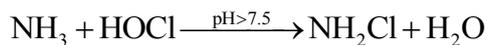
3.9.2 MAJOR METHODS

a) Chlorination



- At pH < 5, chlorine does not react with water and remains as free chlorine.
- (HOCl + OCl⁻ and Cl₂) are combined called freely available chlorine. Out of these forms of freely available chlorine, HOCl is most destructive. It is 80% more effective than OCl⁻ ion. Hence pH of water should be maintained slightly below 7.

- Moreover chlorine will immediately react with ammonia present in water to form chloramines.



- Chloramines are combined form of chlorine. It is less effective than free chlorine (25 times lesser). But they are stable and remain in water for greater duration.
- In the usual chlorine treatment, in which PH is kept slightly less than 7, dichloramine is most predominate.
- These disinfectant kill those enzymes which are essential for the metabolic process of living organism.
- Doses of chlorine should be sufficient so as to leave a residue of 0.2 mg per litre after 10 minutes of contact period. This does is called chlorine demand of water.
- The residual chlorine is tested by DPD (Diethyl-Paraphenylene diamine) test.

3.9.3 FORMS IN WHICH CHLORINE IS ADDED

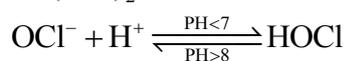
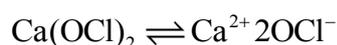
- a) AS free chlorine (liquid or gaseous form).
- b) Hypochlorite's (Bleaching powder).
- c) Chloramines (ammonia + chlorine).
- d) Chlorine dioxide (ClO_2).

3.9.4 FREE CHLORINE

- Liquid form is mostly used.
- If temperature is below 10°C , liquid chlorine will get frozen into ice crystals which will stick and choke the lines of feeding. Hence liquid cylinder is kept at $32 - 48^\circ\text{C}$.
- Steel cylinder burns in dry chlorine at temperature greater than 92°C . Hence high temperature is avoided.
- Chlorine forms explosive mixture with carbon monoxide.
- Chlorine is applied through an equipment called chlorinator.

- Free Chlorine can be stored for long time without being deteriorated.
- Chlorine dose can be easily measured in liquid forms. Hence under loading and overloading is less frequent. Chlorine is a powerful disinfectant and remains in water for a long time when ammonia is present.
- No Sludge is formed in its application as may be produced in Hypochlorites and chloramines.

3.9.5 HYPOCHLORITE OR BLEACHING POWDER [$\text{Ca}(\text{OCl})_2$]



- OCl^- and HOCl^- are the disinfectant in this case. This process is called hypochlorination.
- 100% pure hypochlorite should contain free available chlorine equal to OCl^- value of the compound. E.g. 142 gm of $\text{Ca}(\text{OCl})_2$ will contain 102 gm of OCl^- i.e. free available chlorine in 100% pure calcium hypochlorite is 70%. But the actual chlorinating ability is lesser because bleaching powder is unstable and goes on losing its chlorine content when exposed to atmosphere.
- Hypochlorites are generally not used in modern days because they increase pH because to they are having lime content.
- Hypochlorite contains very low amount of chlorine.
- It is used for swimming pools only.

3.9.6 USE OF CHLORAMINES

- Chloromines are weaker disinfectants (25 times lesser than chlorine). Hence either higher dose or longer contact period is used.
- Chloramines are stable and can remain in water for a long time contrary to unstable chlorine which evaporates after some time. Hence they provide

greater safeguard against future pollution.

- They are weaker as compared to free chlorine but do not cause bad taste when left as residue.
- When phenol is present in water chloramines are mostly used because chlorine with phenols gives bad taste. But chloramines with phenol does not give any taste.
- For producing chloramines ammonia is added to filtered water before adding chlorine.
- Amount of ammonia should be $\frac{1}{3}$ to $\frac{1}{4}$ of the amount of chlorine. They are added in water and mixed for 20 minutes to 2 hours before adding chlorine. This contact period of ammonia should be higher when phenol is present.
- Ammonia adding instrument is called ammoniator.

3.9.7 CHLORINE DIOXIDE (ClO₂)

- It is highly effective (2.5 times stronger than free chlorine).

$$2\text{NaClO}_2 + \text{Cl}_2 \rightarrow 2\text{NaCl} + 2\text{ClO}_2$$
 (ClO₂ is highly unstable hence should be used immediately after production)
- It may also be used when phenol is present and can also remove organic impurities.
- pH range is 8 – 10.
- Normal dose is 0.5 – 1.5 mg/litre.

3.9.8 TYPES OF CHLORINATION

a) Plain chlorination

- Only chlorination and no other treatment is given to water.
- It removes bacteria, organic matter and colour.
- It is used for clean water i.e. turbidity between 20 – 30 mg/l.
- Dose is 0.5 mg/l.

b) Pre Chlorination

- In this case chlorine is added before filtration or rather before sedimentation and coagulation.
- Doses required are such that 0.1 to 0.5 mg/l come to filter.
- Normal dose is 5 to 10 mg/litre and prechlorination is always by post chlorination to ensure safety

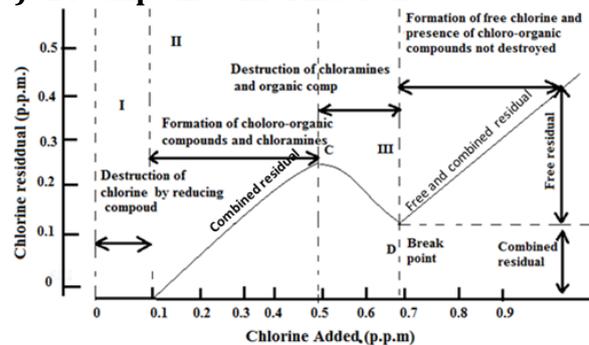
c) Post Chlorination

- Applying chlorine at the end when all treatment is complete is called post chlorination.
- The dose should be such that 0.1 to 0.2 mg/lit should be left after a contact period of 20 min.

d) Double Chlorination

- Prechlorination & post-chlorination combinedly is called double chlorination.

e) Breakpoint Chlorination



- During disinfection process amount of residual chlorine is less in the beginning (stage I) during which iron, nitrite etc. are oxidized.
- In stage II chloramines and combined residual chlorine forms. Combined residual chlorine will gradually increase as demand for disinfection is satisfied.
- Actually chlorine residue is tested by DPD test which measures both combined and free chlorine.
- Amount of residual would be slightly less than applied chlorine because some bacteria killing takes place.
- At point C bad smell start coming out. It is due to the fact that oxidation of organic matter starts at point C. Hence the residual decreases.

- In the stage III free chlorine breaks down chloramines into nitrogen compounds.
 $2\text{NH}_3 + 3\text{Cl}_2 \rightarrow \text{N}_2 + 6\text{HCl}$
- Chloro-organic compounds are also destructed. At point D bad smell suddenly disappears. This implies that organic matter oxidation is complete.
- Any further chlorine addition simply appears as free chlorine i.e. chlorine breaks away from water. Thus point D is called break point.
- In general practice chlorine is added beyond break point to ensure a residual of 0.2 – 0.3 mg/litre as free chlorine. This residual takes care of future recontamination.

Note: The difference of applied chlorine and residual chlorine is called demand of water.

f) Super Chlorination

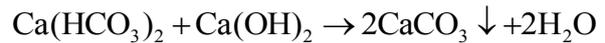
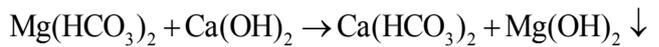
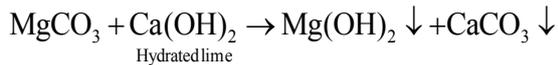
- When excess chlorine (5 to 15 mg/l) is added in water during epidemic such that it gives a residual of 1 to 2 mg/lit beyond break point is called super chlorination.
- When chlorine residue is high excess chlorine will be removed by dechlorinating agent. The various dechlorinating agents are :
 - Sodium thiosulphate ($\text{Na}_2\text{S}_2\text{O}_3$) - cheapest of all.**
 - Activated carbon.**
 - Sulphur dioxide (SO_2).**

3.10 WATER SOFTENING

3.10.1 REMOVAL OF TEMPORARY HARDNESS

- By simple boiling

$$\text{Ca}(\text{HCO}_3)_2 \xrightarrow{\text{Heated}} \underset{\text{ppt.}}{\text{CaCO}_3} \downarrow + \text{H}_2\text{O} + \text{CO}_2 \uparrow$$
- The boiling does not remove temporary hardness due to magnesium, because MgCO_3 is fairly soluble in water. Hence this hardness is removed by addition of lime.



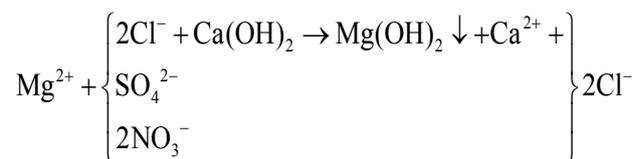
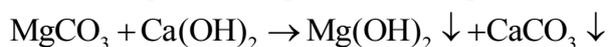
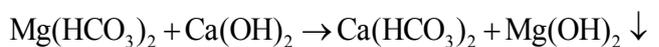
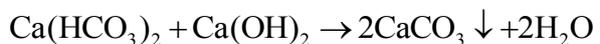
1 mole of MgCO_3 requires a mole of hydrated lime, whereas a mole of $\text{Mg}(\text{HCO}_3)_2$ requires 2 moles of lime.

PPT are removed by sedimentation and filtration through rapid gravity filter.

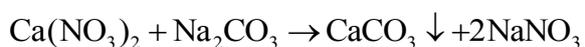
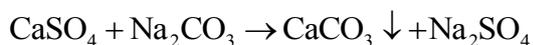
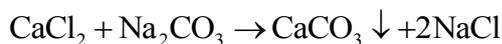
3.10.2 REMOVAL OF PERMANENT HARDNESS (WATER SOFTENING)

- Lime soda process.
- Base exchange process.
- Demineralization process.

3.10.3 LIME SODA PROCES



Further

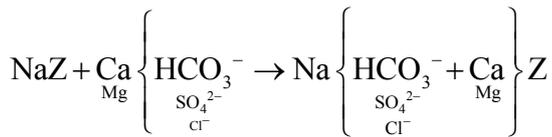


- Lime removes entire carbonate hardness.
- Lime reacts with non-carbonate hardness of magnesium to convert it to non-carbonate hardness of calcium.
- Non-carbonates hardness of calcium is finally removed by soda ash.

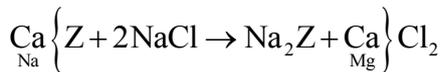
3.10.4 BASE EXCHANGE PROCESS (CATION EXCHANGE PROCESS)

- Zeolite is a natural or synthetic cation or base exchange hydrated silicates of sodium and aluminium. It is called green sand.

Zeolite $\rightarrow \text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot x\text{SiO}_3 \cdot y\text{H}_2\text{O}$ (greensand)



- Thus water will have zero hardness. But sodium zeolite can be regenerated from calcium and magnesium zeolites.
- Regeneration from CaZ_2 and NaZ is done by using 5 - 10% solution (brine solution).

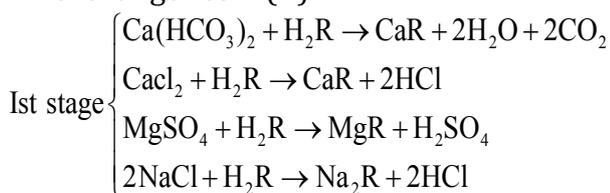


3.10.5 SALIENT POINTS ABOUT ZEOLITE PROCESS

- Zeolite process results in zero hardness.
- No sludge is formed.
- No problem of incrustation of pipe as in lime soda process. But it is not suitable for turbid waters. It also leaves NaHCO_3 in water which causes foaming in boiler feed water.
- The process is costlier for water containing iron and manganese because Fe and Mn zeolites are formed which cannot be regenerated into sodium zeolite. Thus zeolite is wasted, if Fe and Mn are present.

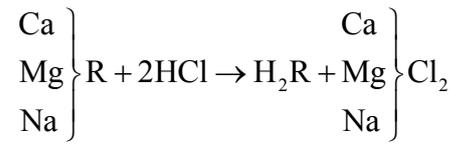
3.10.6 DEMINERALIZATION PROCESS

- This process removes the minerals in water.
- The complete removal is done by first passing the water through cation exchange resins and then through anion exchange resin (R).



- The exhausted cation and anion exchange resins can be regenerated. cation exchange resin can be

regenerated by treating by HCl and anion exchange resin can be regenerated by treating by soda Ash.



↓ ↓
Exhausted C.E.R.
C.E.R.



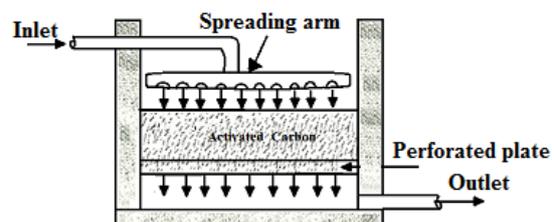
↓ ↓
Exhausted A.E.R A.E.R

- Water with desired hardness can be obtained from water of zero hardness.

3.10.7 MINOR TREATMENTS

a) With activated carbon

- Due to absorption property it removes taste, colour and odour.
- It removes phenol type impurity.
- It is added before or after coagulation but before filtration.
- In split method a part of AC is mixed in mixing tank and remaining is mixed before it enters the filter.
- Usual dose is 5 - 20 mg/l.
- When used with coagulants; it aids in coagulation.
- It reduces chlorine demand of water (because some amount of Cl_2 is used to oxidise organic matter which is removed by activated carbon).
- It also removes organic matter, taste & odour produced by phenol, excess fluorine, H_2S , Fe or Mn.
- Its overdose is not harmful.



b) Treatment with Copper Sulphate ($\text{CaSO}_4 \cdot 7\text{H}_2\text{O}$)

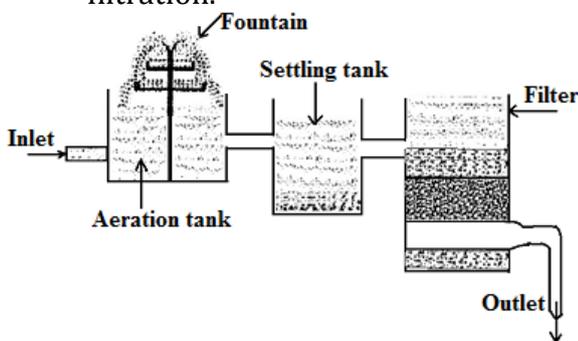
- When added in reservoirs, it checks the growth of algae and kills algae to some extent.
- It also helps in removing colour taste and odour.
- CuSO_4 is added just at the entry of distribution system.
- Usual dose is 0.5 – 0.75 mg/l.

c) Removal of Iron and Manganese

- The presence of iron and manganese in water may be in two forms.
 - (i) Without any organic matter.
 - (ii) In combination with organic matter.

(i) Without any Organic Matter

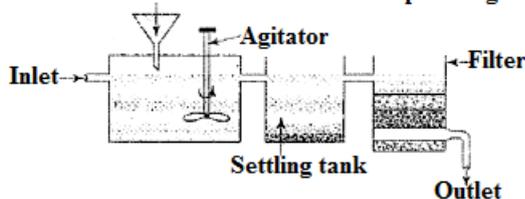
- When Fe and Mn are present without combination with organic matter, they can be removed by simple aeration, sedimentation and filtration.



(ii) In Combination with Organic Matter

- When Fe and Mn exist in water in combination with organic matter, then the bond is broken by adding lime or chlorine or potassium permanganate (KMnO_4).
- The water is agitated thoroughly to break the bond.
- The water is then taken to a settling tank and then to filter unit.

Lime or Chlorine or Potassium permanganate



d) Fluoridation (Addition of Fluorine)

- Agents are NaF (sodium fluoride), Na_2SiF_6 (sodium silico fluoride), H_2SiF_6 (hydro silico acid).

e) DE fluoridation (Removal of Fluorine)

- The following technologies are generally used for removing fluorides from water.
 - i) Absorption by activated alumina (AA), commonly known as Prashanti technology.
 - ii) Nalgonda technique.
 - iii) Ion exchange adsorption method.
 - iv) Reverse osmosis process.

i) Prashanti Technique

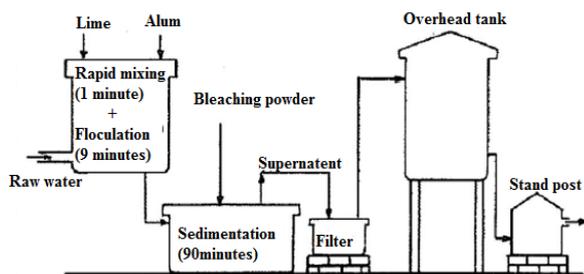
- In this method raw water containing high contents of fluorine, is passed (percolated) through the insoluble granular beds of activated alumina (AA), or activated carbon; which adsorbs fluoride from the percolating water, giving out defluoridated water.
- Activated alumina is an excellent medium for removal of excess fluoride than other adsorption media.
- The adsorption process is best carried out under slightly acidic condition ($\text{pH} = 5$ to 7).

ii) Nalgonda Technique

- Mainly used in rural areas, ground water containing excess fluoride.
- Nalgonda technique uses aluminium salt (alum) for removing fluoride.
- The raw water is firstly mixed with adequate amount of lime (CaO) or sodium carbonate (Na_2CO_3) and thoroughly mixed.
- Alum solution is then added, and water is stirred for about 10 min, and allowed to settle for nearly one hour.
- The precipitated sludge is discarded, and the clear supernatant

containing permissible amount of fluoride is withdrawn for use.

- The line diagram for the process is



iii) Iron Exchange Adsorption Method

- This process is almost similar to that used for removing hardness from water, however uses a strong base anion exchange resin (zeolite) in the chloride form.

iv) Reverse Osmosis Process

- In this method, the raw water is passed through a semipermeable membrane barrier, which permits the flow of clear water through itself and block, the flow of salts including fluorides.

f) Desalination

- It is done by reverse osmosis (RO) process.
- It is done by electro dialysis.
- In electro dialysis treatment process, dissolved salts from water are separated by passing an electric current through the water tank, installed with ion exchange membranes.

g) Removal of Toxic Metals

- They are removed by coagulation sedimentation process. By adding coagulants like and maintain a proper pH value, the toxic metal precipitates and removed in sedimentation process.

4

DISTRIBUTION SYSTEM

4.1 DISTRIBUTION OF WATER

4.1.1 REQUIREMENT OF GOOD DISTRIBUTION

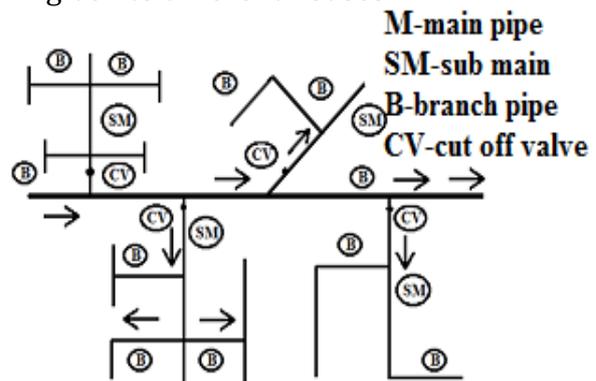
- Water quality should not get deteriorated in the distribution pipes.
- It should be capable of supplying water at the intended place with sufficient pressure heads.
- It should be capable of supplying the requisite amount of water during fire fighting.
- The system layout should be such that no consumer would be without water supply during the repair of any section of the system.
- All the distribution of pipes should be preferable laid one meter away or above the sewer line.
- It should be fairly water-tight as a keep losses due to leakage minimum
- There is no chance of any contamination.

4.2 LAYOUTS OF DISTRIBUTION SYSTEM

- The distribution pipe system consists of mains, sub-mains, branches, laterals and finally service connections.
- Pipes, except the service connections, are usually made of cast iron with some type of coating to avoid rusting whereas for service connections galvanized cast iron pipes are used.
- Distribution pipe are mostly laid along the road below the footpath. Depending upon local conditions and orientation of roads, any of the following pattern of layouts is adopted singly or in combination.
 - i) Dead end or tree system.
 - ii) Grid system or reticular system.
 - iii) Ring or circular system.
 - iv) Radial system.

4.2.1 DEAD END SYSTEM

- The system is also known as tree system.
- The system has one main pipe from which a number of submains bifurcate and from each submains several branched pipes separate out which are known as laterals.
- From laterals house connection are given to different houses.

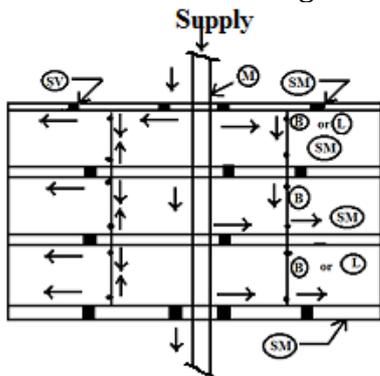


- Such type of distribution system is followed for old towns where the houses come up in a very unplanned way.
- System is easy to design and is cheap and simple, there are some drawbacks.
 - Water can reach at a particular point only through one route, hence, if some fault creep in, water supply gets disturbed in that area because water conveyance is unidirectional only.
 - There are many dead ends which prevent free circulation of water.
 - Stagnant water has to be removed periodically by providing scour valves at dead ends, and this results in wastage of treated water.

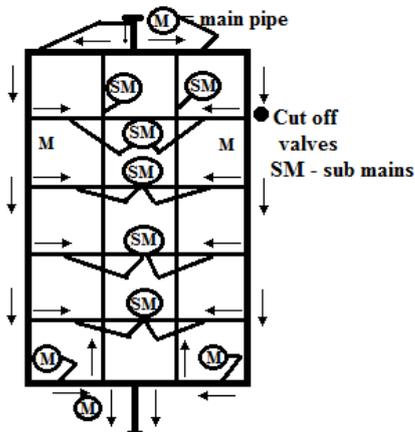
4.2.2 GRID SYSTEM

The system is also known as reticular system.

- In this system one main pipe runs through centre and branches and laterals run in grid pattern which are inter-connected as shown figure.



M-main pipe, SM-sub main,
B-branches or laterals,
SV-scour valves



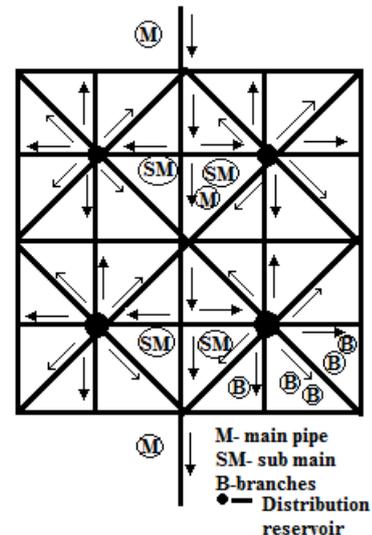
- Since the mains, branches and laterals are inter-connected hence dead ends are eliminated and water reaching at different locations through more than one route.
- At the time of fire, water can be diverted to the affected area by closing cut-off valves of other areas.
- Since the pipe lines get water from different directions, design is a bit difficult, size of pipes are larger and more number of sluice valves are required.
- The system is most suited for a planned city where roads and streets are provided in planned rectangular and square grid patterns.
- The system is also known as interlaced system.

4.2.3 DISADVANTAGE

- This system requires more length of pipe lines, and a large number of sluice valve (i.e. cut-off valves).
- The design is difficult and costlier.

4.2.4 RING SYSTEM

- The system is also known as circular system.
- The system consists of a main pipe all round the area.



4.2.5 RADIAL SYSTEM

- A very big area is divided in several zones and at the centre of each zone a distribution reservoir is kept.
- This method gives higher service head and efficient water distribution.

4.2.6 PIPE NETWORK ANALYSES

- In any pipe network the following two condition must be satisfied:
 - The algebraic sum of pressure drops around a closed loop must be zero i.e. there can be no discontinuity in pressure.
 - The flow entering a junction must be equal to the flow leaving that junction i.e. the law of continuity must be satisfied.

5

WASTE WATER CHARACTERISTICS

5.1 INTRODUCTION

- Waste waters are usually classified as industrial waste water or municipal waste water.
- Industrial waste water with characteristic compatible with municipal waste water is often discharged to the municipal sewers.
- Many industrial waste waters require pretreatment to remove non-compatible substances prior to discharge into the municipal system.
- Water collected in municipal waste water system contains a wide variety of contaminants. Commonly found contaminants with their source and environment.

Important Waste Water Contaminates

| Sl. NO | Contaminant | Sources | Environmental Significance |
|--------|-----------------------|---------------------------------|---|
| 1 | Suspended solids | Domestic use, Industrial wastes | Causes sludge deposits and Anaerobic condition in aquatic environment |
| 2 | Biodegradable Organic | Domestic use, Industrial wastes | Cause biological degradation |
| 3 | Pathogens | Domestic water | Transmit communicable diseases |
| 4 | Nutrients | Domestic and Industrial waste | Cause eutrophication |
| 5 | Refractory Organics | Industrial waste | Causes taste and odour Problems |

Hence, it is very necessary to study the characteristics and behavior of sewage, for its safe disposal. This study will also help us in determining the type of treatment required.

5.2 PHYSICAL CHARACTERISTICS

The most important physical characteristics of water is its turbidity, colour, odour and temperature.

5.2.1 TURBIDITY

Waste water is normally turbid, containing wastes from baths, faecal matter, pieces of papers, greases, vegetable debris, fruit skins, etc.

5.2.2 COLOUR

- The colour of waste water can normally be detected by the naked eye, and it refers to the age of waste water.
- Fresh waste water is usually gray or light brown, however, as organic compounds are broken down by bacteria, the dissolved oxygen in the waste water is reduced to zero and colour changes to black, this condition of waste is said to be septic or stale.
- Some industrial waste waters may also add colours to the domestic waste water.
- The common method of colour removal is by coagulation followed by sedimentation.

5.2.3 ODOUR

- Odours in waste water usually are caused by gases produced by the decomposition of organic matter.
- The most characteristics odour of stale or septic waste water is that of hydrogen sulphide, which is produced by anaerobic microorganisms that reduce sulphates to sulphides.

5.2.4 TEMPERATURE

The average temperatures of sewage in India is 20°C, which is near about the ideal temperature for the biological activities.

5.3 CHEMICAL CHARACTERISTICS

Important chemical characteristics of waste water are listed below :

- i) Total solids, suspended solids and Settleable solids.
- ii) pH value.
- iii) Chloride content
- iv) Nitrogen content
- v) Presence of fats, greases, and oils.
- vi) Sulphides, sulphates and H₂S gas.
- vii) Dissolved oxygen.
- viii) Chemical oxygen demand (COD).
- ix) Bio-chemical oxygen demand (BOD).
- x) Total organic carbon (TOC).
- xi) Theoretical oxygen demand (ThOD).

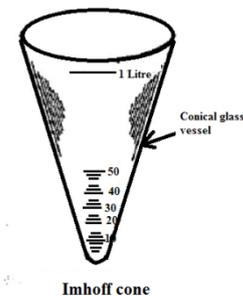
5.3.1 TOTAL SOLIDS, SUSPENDED SOLIDS AND SETTLEABLE SOLIDS

Solids present in waste water may be in four forms : suspended solids, dissolved solids, colloidal solids and settlement solids.

- Suspended solids, are those which remain floating in water.
- Dissolved solids are those which dissolve in waste water.
- Colloidal solids are finely divided solids remaining either in suspension or in Solution.
- Settleable solid are that portion of solid matter which settle out, if the waste water is allowed to remain undisturbed for a period of 2 hours.
- The solids in waste water has organic solids as well as inorganic solids, which is about 45 and 55 per cent of total solid respectively.
- Inorganic matter consists of sand, gravel, debris, chlorides, sulphates etc, whereas organic matter consist of :
 - i) Carbohydrates such as cellulose, cotton, fibre, sugar etc.
 - ii) fats and oils from kitchens, garages, shops etc.
 - iii) nitrogenous compounds like proteins, urea, fatty acids etc.

The amount of various kinds of solids present in waste water can be determined as follow :

- a) Total amount of solids can be determined by evaporating a known value of waste water sample, and weighting the dry residue left. The mass of residue left divide by the volume of sample is total solids in mg/l.
- b) The suspended solids, also called non-filterable solids, as they are retained on a filter of 1 μ m pores. Thus weighting the dry residue left and dividing by volume of sample filtered will give suspended solids in mg/l.
- c) The quantity of settlement solids can be determined using Imhoff cone (figure). Waste water is allowed to stand in the cone for two hours and the quantity of solids settled down in the bottom is directly read out, which gives an approximate amount of settlement solids.



Imhoff cone

5.3.2 pH VALUE

- The determination of pH value is very important, as it gives an idea about certain treatments which depends upon pH value.
- The pH value can be measured by the help of potentiometer which measure the electrical potential exerted by hydrogen ions, and thus indicating their concentrations.
- The alkalinity of fresh, waste water sample is alkaline but as time passes it becomes acidic, because of the bacteria action in anaerobic or nitrification processes.

5.3.3 CHLORIDE CONTENT

- These are derived from the kitchen wastes, human faeces, and urinary discharges etc. The normal chloride content of domestic waste water is 120 mg/l, however, large amount of chlorides may enter from industries like ice-cream plants, meat salting etc., thus increasing the chloride content of waste water.
- The chloride content can be measure by titrating the sample of waste with standard silver nitrate solution, using potassium chromate as an indicator.

5.3.4 NITROGEN CONTENT

- The presence of nitrogen in waste water indicates the presence of organic matter, and may be found, in the following forms :
 - a) Free ammonia or ammonia nitrogen (indicates recent pollution)
 - b) Albuminoid nitrogen or organic nitrogen (indicates quantity of nitrogen before decomposition has started).
 - c) Nitrites (indicates partly decomposed condition).
 - d) Nitrates [indicates old pollution (fully oxidized)]

5.3.5 PRESENCE OF FACTS. OILS AND GREASES

- Facts and oils are compounds of alcohol or glycerol with fatty acids.
- Such matter form scum on the top of the sedimentation tanks and clog the voids of the filtering media. Therefore, they interfere with the normal treatment methods, and hence need proper detection and removal.
- The amount of facts and greases in waste water sample can be determined by evaporating it and then mixing the residual solids left, with ether (hexane). The solution is then poured off and

evaporated, leaving behind the facts and greases as residue, which can be easily weighted.

5.3.6 SULPHIDES, SULPHATES AND HYDROGEN SULPHIDE GAS

- Sulphides and sulphates are formed due to decomposition of various sulphur containing substances present in waste water.
- This decomposition also leads to evolution of hydrogen sulphide gas, causing bad smells and odours, besides causing corrosion of concrete sewer pipes.
- The initial decompositions is associated with formation of H_2S gas, which also ultimately gets oxidized to form sulphates ions.

5.3.7 DISSOLVED OXYGEN

- Dissolved oxygen is required for the respiration of aerobic micro-organisms as well as all other aerobic life forms.
- The dissolved oxygen in fresh waste water depends upon temperature. If the temperature of sewage is more, the D.O. content will be less. Max quantity of D.O. that can remain mixed in water at a particular temperature is called Saturation Dissolved Oxygen.
- Dissolved oxygen less than 4 ppm is detrimental to the survival of fish.
- The D.O content of waste water is determined by the **Winkler's Method**.

5.3.8 CHEMICAL OXYGEN DEMAND (COD)

- The COD test is used to measure the content of organic matter of waste water. Both biodegradable and non-biodegradable.
- The oxygen equivalent of organic matter that can be oxidized is measured by using a strong chemical oxidizing agent in an acidic medium.

- Potassium dichromate has been found to be excellent for this purpose.
- This test is also sometimes called dichromate-oxygen demand test.
- (COD-BOD_μ)= No biodegradable organics.

5.3.9 THEORETICAL OXYGEN DEMAND (THOD)

If the chemical formula and the quantity of all organic matter present in the sewage is known, the exact amount of oxygen required to oxidize then can be calculated stoichiometrically. This is called theoretical oxygen demand (ThOD).

For most practical cases, COD = ThOD(taken), However, generally ThOD > COD > BOD > TOC

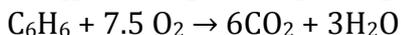
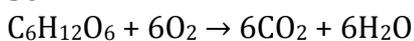
5.3.10 TOTAL ORGANIC CARBON (TOC)

It is another method of expressing the organic matter in terms carbon content. The following example will illustrate it.

Example 1

Calculate theoretical oxygen demand and organic carbon concentration of water that contains 200 mg/l of glucose (C₆H₁₂O₆) and 25 mg/l of benzene (C₆H₆).

Sol



$$\text{ThOD} = \frac{192}{180} \times 200 + \frac{240}{78} \times 25$$

$$= 290.2 \text{ mg/l}$$

$$\text{TOC} = \frac{72}{180} \times 200 + \frac{72}{78} \times 25$$

$$= 80 + 23.08 + 103.08 \text{ mg/l.}$$

5.4 BIO-CHEMICAL OXYGEN DEMAND

- Bio-chemical oxygen demand is used as a measure of the quantity of oxygen required for oxidation of bio degradable organic matter present in water sample by aerobic biochemical action.

- Oxygen demand of waste water is exerted by three classes of materials :
 - a) Carbonaceous organic materials.
 - b) Oxidisable nitrogen derived from nitrite, ammonia and other organic nitrogen compounds which serves as food for specific bacteria (Nitrosomonas and nitrobactor).
 - c) Chemical reducing compounds e.g. Fe²⁺, SO₃²⁻ (sulphites), SO²⁻ (sulfide) which are oxydised by dissolved oxygen.
- For domestic sewage, nearly all oxygen demand is due to carbonaceous organic material and is determined by BOD test.

Note: When nitrogenous matter is also to be removed in treatment process. Nitrogenous Demand is also found out. This is called N-BOD (i.e. O₂ required for conversation of Nitrogenous matter to nitrate). Removal of nitrogen from the system is achieved by 1st oxydising the nitrogenous organic matter to nitrate (i.e. nitrification) and then denitrifying the nitrate to release nitrogen gas (N₂) which goes out of the waste Water.

- The BOD can be determined by diluting a known volume of a sample of waste water with a known volume of aerated pure water, and then calculating the D.O. of this diluted sample. The diluted sample is then incubated for 5 days at 20°C. The
- D.O. of the diluted sample, after this period of incubation, is again calculated.
- The difference between the initial D.O. value and the final D.O. value will indicate the oxygen consumed by the diluted sewage sample in 5 days. The BOD in ppm is then calculated by using the equation :

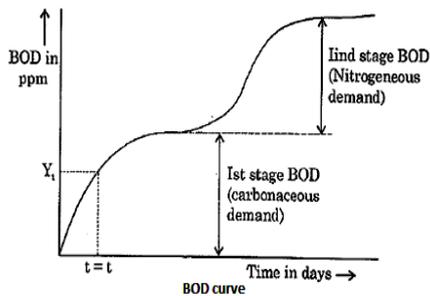
BOD or BOD₅ = D.O. consumed in the test by diluted sample

$$\times \left[\frac{\text{Vol. of the diluted sample}}{\text{Vol. of the undiluted sewage sample}} \right]$$

The above factor in the bracket is called dilution factor.

Note Sample is diluted with dilution water so that sufficient oxygen is available during the incubation period of 5-days.

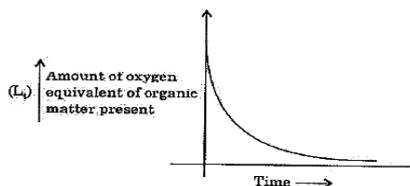
- The first demand occurs due to oxidation of organic matter and is called **Carbonaceous demand** or first stage demand, and later demand occurs due to biological oxidation of ammonia, and is called **nitrogenous demand** or second stage demand.
- However, the term BOD, usually mean the first stage BOD.



- Nitrogenous demand starts only after 5-8 days because the reproduction rate of nitrification bacteria is slow.

Note: Nitrification bacteria are autotrophes. They derive carbon for their growth from CO₂. Hence they have to spend energy in reducing 'CO₂' to 'C'. Thus energy available for their reproduction is less thereby growth rate is less. Carbonaceous matter oxidising bacteria are heterotrophes. They derive carbon from organic matter directly. Hence energy is not spent in getting carbon. Thereby their reproduction rate is more.

5.4.1 REACTION KINETICS



L_t = amount of organic matter present at time t

$$\frac{dL_t}{dt} = -kL_t$$

Where, k = reaction constant

$$\int_{L_0}^{L_t} \frac{dL_t}{L_t} = \int_0^t -k dt$$

$$\Rightarrow \log_e L_t - \log_e L_0 = -k(t-0)$$

$$\log_e \left(\frac{L_t}{L_0} \right) = -kt$$

$$\Rightarrow L_t = L_0 e^{-kt} \text{ ----- (i)}$$

From (i) we have

$$2.303 \log_{10} \left(\frac{L_t}{L_0} \right) = -kt$$

$$\Rightarrow \log_{10} \left(\frac{L_t}{L_0} \right) = \frac{-kt}{2.303}$$

$$\Rightarrow L_t = L_0 e^{-k_D t}$$

Where, $K_D = \frac{k}{2.303} = 0.434k$ $BOD_t = L_0 - L_t$

$$= L_0 - L_0 e^{-k_D t}$$

$$BOD_t = L_0 (1 - 10^{-k_D t})$$

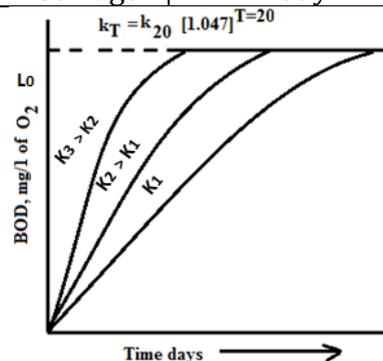
- Unit of K_D is in terms of per day and it is temperature dependent.

$$K_{D(T^0)} = K_{D(20^0)} [1.047]^{T-20^0}$$

(vanthoff-Arrhenius equation)

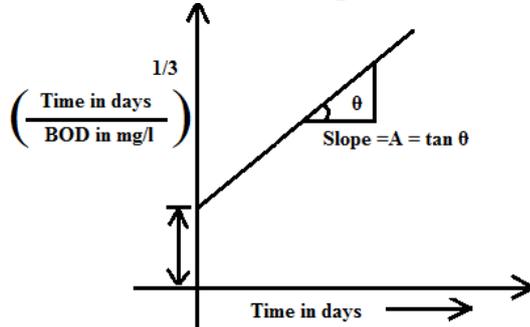
- K_D is also sometimes called deoxygenating constant.

| Water type | K_D Value |
|------------------|--------------------|
| Tap water | < 0.05 per day |
| Surface water | 0.05 – 0.1 per day |
| Municipal sewage | 1.0 – 0.15 per day |
| Treated sewage | 0.05 – 0.1 per day |



- If the value of constant is given more than the normal range, it is understood that it given in terms of base 'e'.

5.4.2 ESTIMATION OF K_D



$$K_D = 2.61 \frac{A}{B} \text{ Per day}$$

5.4.3 POPULATION EQUIVALENT

- Average standard BOD of domestic sewage is 80 gms per person per day.
- The number of person which produce the amount of BOD at the rate of 80 gms per person per day equal to that produced by industrial sewage is called population equivalent of industrial sewage.

5.4.4 RELATIVE STABILITY (S)

- Relative stability (S) is calculated as

$$S = \frac{O_2 \text{ available in effluent}}{\text{Total } O_2 \text{ required for 1st stage BOD}}$$

$$S = 100 \left[1 - (0.794)^{t_{20}} \right] = 100 \left[1 - (0.63)^{t_{37}} \right]$$
 Where t_{20}/t_{37} = time in days for a sewage sample to decolourise a sample of methylene blue solution when incubated at 20° and 37° respectively.
- Decolourisation is caused by enzymes produced by anaerobic bacteria.
- The sooner the decolourisation takes place, the earlier the anaerobic condition develops which means lesser availability of oxygen.
- The decolourisation takes place in less than a day at 20°C, the effluent may be treated as unstable. If sample does not

decolourise in 4 days it will be taken as stable and thus the effluent can be discharged into the river.

- This relative stability check is a performance check test for the treatment process.

Note : If BOD of domestic sewage is to be found out, we collect samples.

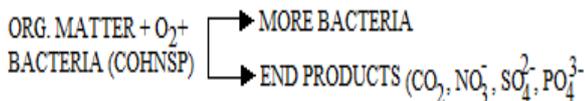
- To prevent biological action from taking place preservatives like chloroform, formaldehyde, H_2SO_4 are added in the bottle.
- The samples collected at different times have different BOD and all such samples are mixed in proportion to the rate of flow at the time of collection. This is done to get a representative sample.
- Physical and chemical characteristics of sewage vary from top to bottom depth of sewage. So, a representative sample from a point where thoroughly mixed up The sewage is called grab sample.

5.5 AEROBIC & ANAEROBIC REACTIONS

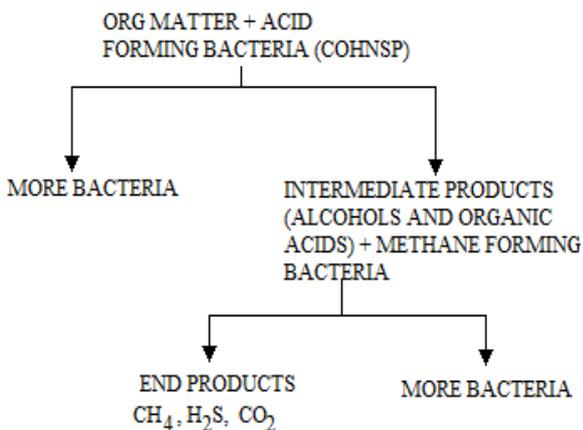
- The aerobic and anaerobic are the two basic forms of biological stabilization reactions whose occurrence is dependent upon the availability or dissolved oxygen.
- Aerobic reactions take place in the presence of free oxygen and produce reasonably stable inorganic end products with relatively low energy contents.
- A considerable portion of the organic matter is synthesised to new microbial cells.
- The reaction provides high degree of stabilization although the synthesized microorganisms result in the formation of large volumes of sludge which require further treatment.
- Anaerobic reactions occur only in the absence of free oxygen.
- They are more complex because they occur in two stages carried out by different species of bacteria.

- Acid-forming bacteria initially convert complex organics into organic acids and alcohols. At this point methane-forming bacteria convert the acids and alcohols into methane and other end products such as hydrogen sulphide.
- The end products of anaerobic reactions still contain considerable amounts of energy, notably in the methane.
- Because of the lower release of energy in anaerobic stabilisation of new cells is very much less than in aerobic reactions.
- This means that there is less sludge from anaerobic stabilisation of a wastewater than from aerobic stabilisation of the same wastewater.
- Anaerobic reactions are much slower than aerobic reactions and do not usually remove the organic content of the food to such a low level as it is possible in an aerobic reaction.

Note : In anaerobic process, bounded O_2 is removed from the molecules and thus energy released in anaerobic process is less and hence synthesis of new cell is less.



Aerobic Reaction

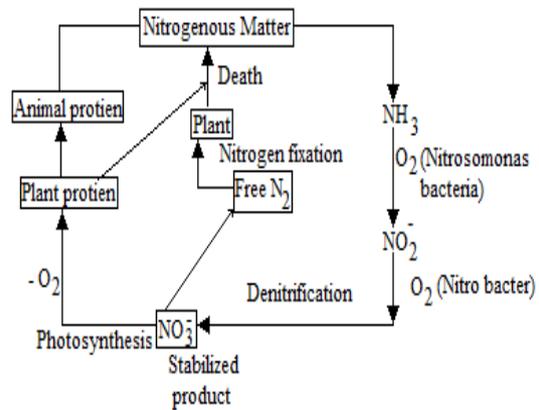


Anaerobic Reaction

5.6 VARIOUS NATURAL CYCLES

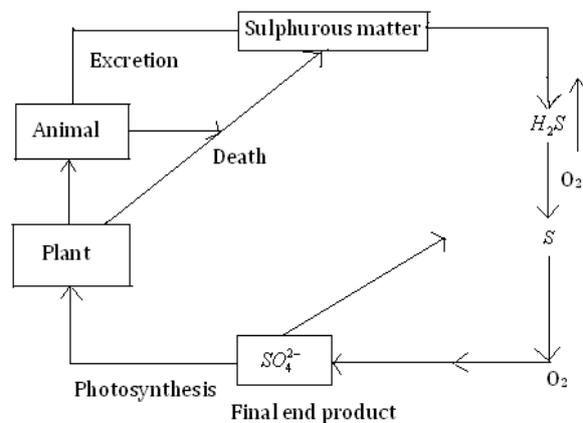
- 1) Aerobic cycle
- 2) Anaerobic cycle

(i) Aerobic Cycle



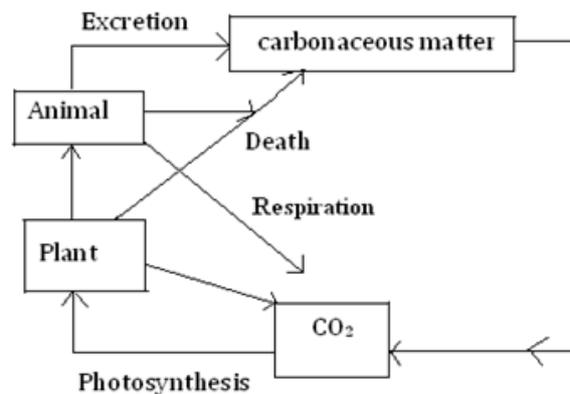
Nitrogen cycle (Aerobic cycle)

(ii) Sulphur Cycle



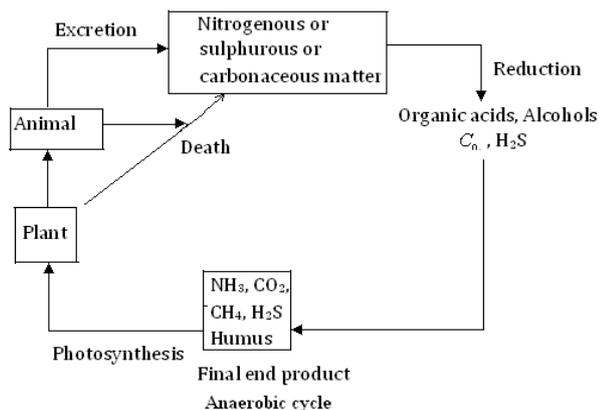
Sulphur Aerobic cycle

(iii) Carbon Cycle



Carbon Aerobic cycle

(iv) Anaerobic Cycle



5.7 VARIOUS TYPE OF BACTERIA

- Bacteria are primary decomposers organic material. They utilize soluble food.
- Bacteria require energy and material for growth and reproduction.
- Energy for bacteria is derived from biochemical oxidation or reduction of inorganic or organic compounds.
- Material is derived from inorganic and organic compounds.

Bacteria are classified according to the energy or material source they require.

Autotrophs: They derive both enough energy and material from inorganic substance.

Heterotrophs : They derive both energy and material from organic compounds.

Phototrophs : Utilise sunlight as energy source and inorganic substances for material sources.

Heterotrophic bacteria are the most important species in the degradation of organic matter.

Aerobic hetrotrophs: Aerobic bacteria (normally called) utilizes organics in the presences of oxygen.

Anaerobic hetrotrophs: Anaerobic bacteria utilizes organic in the absence of oxygen.

Facultative hetrotrophs: Facultative bacteria is capable of functioning both in presence as well as absence of oxygen.

6

TREATMENT

6.1 TREATMENT METHODS

Usually, physical, Chemical or Biological means are applied for wastewater to carry out specific function on the principles of either one or a combination of the means employed. Based on the means used, treatment methods have been broadly classified as unit operations and unit processes.

6.1.1 UNIT OPERATIONS

The means of treatment in which the application of physical forces predominates are known as unit operations. Major treatment methods falling under this category are screening, mixing, sedimentation, etc.

6.1.2 UNIT PROCESS

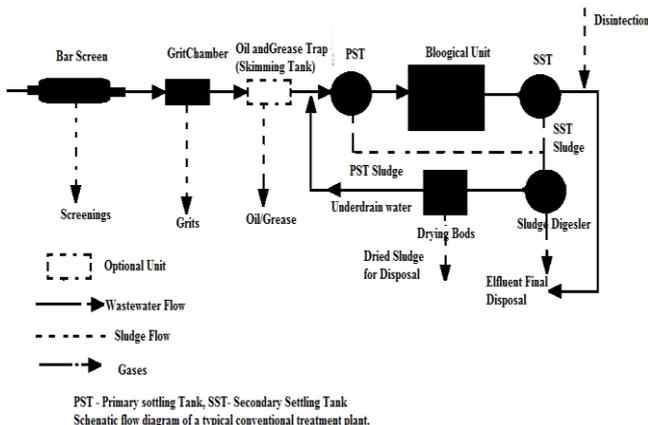
The types of treatment in which the removal of contaminates is brought about by the addition of chemicals or the use of biological mass or microbial activities are known as unit process. Based on the type of agent used biological unit process are

i) Suspended growth process.

Example: Activated Sludge Process, Aerated Lagoon, Oxidation Pond, Aerobic & Anaerobic Digester etc

ii) Attached growth process.

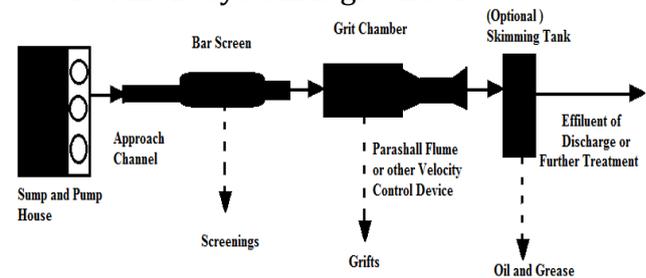
Example: Trickling Filter, Rotating Biological contactors, Bio-Towers etc.



The type of combinations used from the available unit operations and process for treatment of a particular wastewater is known as the treatment system. A wastewater treatment plant is designed for either of the following treatment system.

1) Preliminary Treatment System

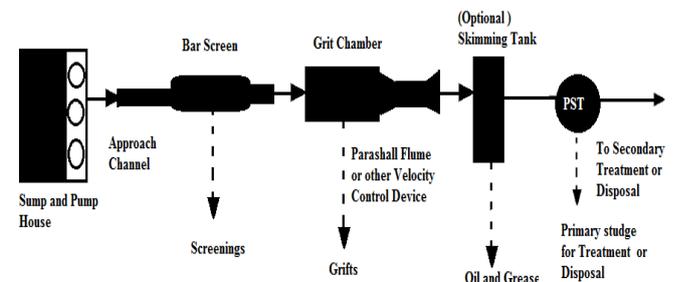
The preliminary Treatment System is mainly selected to remove floating materials and large inorganic particulate contents of wastewater. The preliminary treatment systems are screen chamber, grit chamber and skimming tank (oil and grease traps) A flow diagram of a typical preliminary treatment system is given below



Flow diagram of a typical preliminary treatment system

2) Primary Treatment System

The primary treatment system includes all the units of the preliminary treatment system and primary sedimentation tank (PST), also known as primary clarifier.



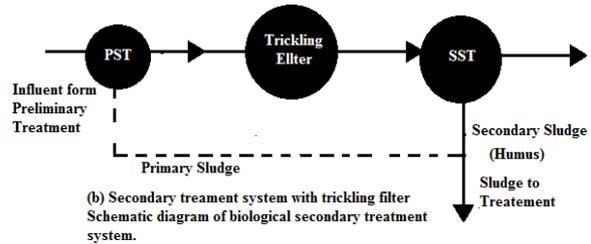
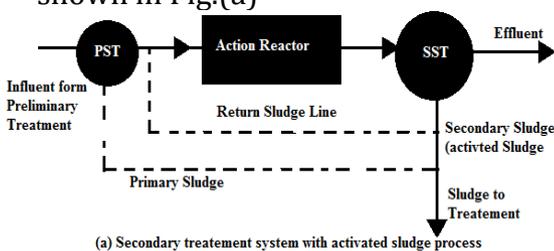
Schematic diagram of typical primary treatment system.

- The purpose of primary treatment is to remove suspended solid materials from the incoming waste water.
- It will not remove the colloidal and soluble (dissolved) organic content of waste water.

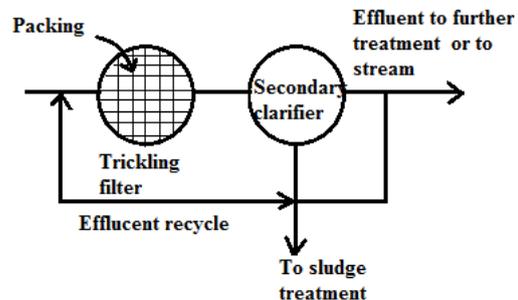
- Large debris is removed by screen or may be reduced in size by grinding devices.
- Inorganic solids are removed in grit channels.
- Organic suspended solids are removed in sedimentation tank.
- Disposal of inorganic matter is convenient because it does not decompose. But, disposal of organic matter is difficult because if it is disposed untreated, it will create nuisance. Hence it is desired that inorganic and organic matters are removed in two different units.
- Primary treatment removes approx. 60-70% of suspended solid.
- The BOD associated with these solids account for approx. 30% of influent BOD. Hence 30% of influent BOD is removed in 1⁰ treatment.

3) Secondary Treatment System

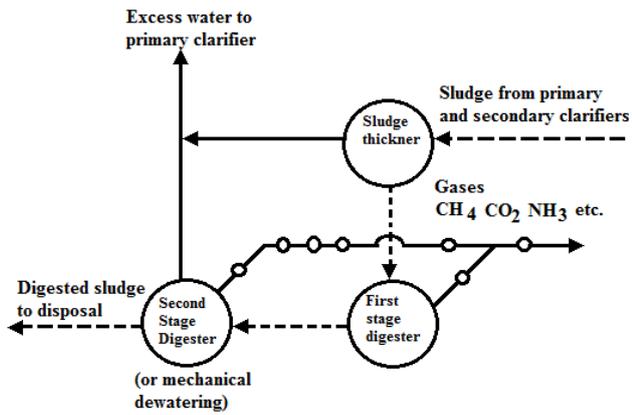
- After primary treatment, its wastewater is further treated for the removal of colloidal and soluble organic matter present in wastewater, then it is called secondary treatment of wastewater.
- Secondary treatment usually consists of biological conversion of dissolved and colloidal organics into biomass that can subsequently be removed by sedimentation.
- Contact between microorganisms and the organics is optimized by suspending the biomass in the wastewater or by passing the wastewater over a film of biomass attached to solid surfaces.
- The most common suspended biomass system is the activated-sludge process shown in Fig.(a)



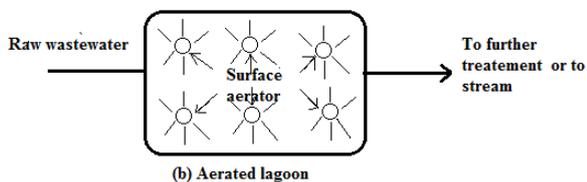
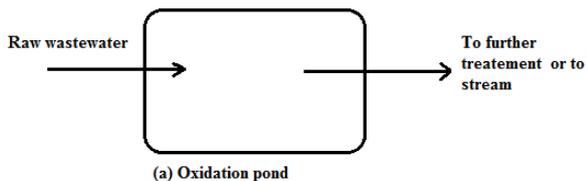
- A part of settled sludge in secondary clarifier is recycled back to aerator.
- Recirculating a portion of the biomass maintain a large number of organisms in contact with the wastewater and speeds up the conversion process.
- The classical attached-biomass system is the trickling filter. Stones or other solid media are used to increase the surface area for biofilm growth. Mature biofilms peel of the surface and are washed out to the settling basin with the liquid underflow. part of the liquid effluent may be recycled through the system for additional treatment and to maintain optimal hydraulic flow rates.



- Secondary systems produce excess biomass that is biodegradable through endogenous catabolism and by other microorganisms.
- Secondary sludge are usually combined with primary sludge for further treatment by anaerobic biological processes. The results are gaseous end products, principally methane (CH₄) and carbon dioxide (CO₂), liquids and inert solids.
- The methane has significant heating value and may be used to meet part of the power requirements of the treatment plant.
- The liquids contain large concentrations of organic compounds and are recycled through the treatment plant.



- The solid residue has a high mineral content and may be used as a soil conditioner and fertilizer on agricultural lands.
- Other means of solids disposal may be incineration or by land filling.
- Sometimes primary and secondary treatment can be accomplished together. The oxidation pond most nearly approximates natural systems, with oxygen being supplied by algal photosynthesis and surface reiteration. This oxygen seldom penetrates to the bottom of the pond, and the solids that settle are decomposed anaerobically.



- In the aerated lagoon system, oxygen is supplied by mechanical aeration, and the entire depth of the pond is aerobic.
- Decomposition of the biomass occurs by aerobic endogenous catabolism.
- The small quantity of excess sludge that is produced is retained in the bottom sediments.

4) Tertiary Treatment

- In most cases, secondary treatment of municipal wastewater is sufficient to meet effluent standards. In some instances, however, additional treatment may be required.
- Tertiary treatment most often involves further removal of suspended solids and/or the removal of nutrients.
- Solids removal may be accomplished by filtration, and phosphorus and nitrogen compounds may be removed by combinations of physical, chemical, and biological processes.

6.2 PRIMARY TREATMENTS

6.2.1 SCREENING

It is used for removal of certain materials such as pieces of wood, floating debris, leaves, rags, etc. found in sewage. Primary purpose of screen is to pump and other mechanical equipments. Hence screening is normally the 1st operation performed on the incoming waste water. Depending on the clear spacing. The screens shall be classified as under:

- a) Coarse screens Above 50 mm
 - b) Medium screens 20 to 50 mm
 - c) Fines screens Less than 20 mm
- Bars are usually 10 mm thick.

Location

- Screening devices generally precede grit chamber and pumps. Screens shall preferably be installed in open channels.
- For facility of manual cleaning of the screen, inclination shall be between 45° and 60° to the horizontal.
- Head loss through screen (bar screen)

$$h_L \text{ (m)} = 0.0729 (V^2 - v^2)$$

$$V = \text{velocity through opening of bar screen (in m/s)}$$

$$v = \text{approach velocity in upstream channel (in m/s)}$$

Example 1

A bar screen is installed in a wastewater treatment plant receiving a daily peak flow of crude sewage of 50,000 m³. Estimate the head loss through the screen and also the gross area of the screen (i.e., the screen requirements). Take desired velocity of flow through screen = 0.8 m/s

Also calculate the head loss when $\frac{1}{2}$ of the screen is plugged due to leaves and debris.

Solution

Maximum flow, $Q = 50,000 \text{ m}^3/\text{d} = 0.5788 \text{ m}^3/\text{s}$

Desired velocity through screen, V , at ultimate flow = 0.8 m/s

Net area of screen, $A = 0.5788/0.8 = 0.72 \text{ m}^2$ (since $Q = VA$)

Adopting screens with bars of 10 mm width (dia) and 50 mm clear opening, the gross area (including bars) would be

$$\frac{0.72 \times 60}{50} = 0.86 \text{ m}^2$$

Velocity through screen = 0.8 m/s

Velocity above screen,

$$u = \frac{0.8 \times 50}{60} = 0.67 \text{ m/s}$$

(using the equation of continuity)

Headloss through screen is usually given as

$$0.0729(V^2 - u^2) = 0.0729(0.8^2 - 0.67^2) = 0.013$$

If the screen openings are half plugged with screenings, leaves and debris, the velocity through the screen is doubled.

Maximum head loss = $0.729 (1.6^2 - 0.67^2)$

$$= 0.0729 \times 2.27 \times 0.93$$

$$= 0.15 \text{ m}$$

At this maximum head loss, the screen has to be cleaned.

Assuming that the inclination of the screen to the horizontal is at 60°, the gross area of screen needed would be :

$$\frac{0.86}{\sqrt{3/2}} = 0.9931 \text{ m}^2 = 1 \text{ m}^2$$

6.2.2 COMMUNICATION & MACERATION

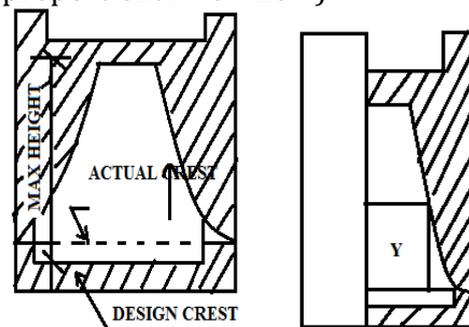
They are installed before fine screen. They shed materials to size 6-20 mm.

Comminutors has cutting teeth whereas macerator have grinding wheels.

6.2.3 GRIT CHAMBER

Grit removing devices are located either before or after sewage pumps in sewage treatment plants to prevent clogging of pipelines, channels, etc. due to settlement of grit. They separate non-decaying heavy inorganic material from sewage so that inorganic material may be disposed off without causing nuisance. They also assist in prevention of grit accumulation in digesters and clarifiers, and, in general, in protecting all the machinery used in sewage treatment plant. Removal of grit also reduces the frequency of cleaning of digesters and settling tank.

- Grit chambers are provided in the form of channels of longer length and smaller x-sec. area.
- Grit chamber should not allow settlement of organic materials.
- Velocity in the grit chamber should be such that organic matters do not settle. Or it has settled, the velocity should be sufficient to scour away the settled organic matter.
- Two channels are provided one for normal flow and other for peak flow, obviously used with normal flow.
- Only one section (channel) is required if velocity control devices has been used e.g., proportional flow weir, or Parshall flume or sutor weir. (is half proportional weir flow)



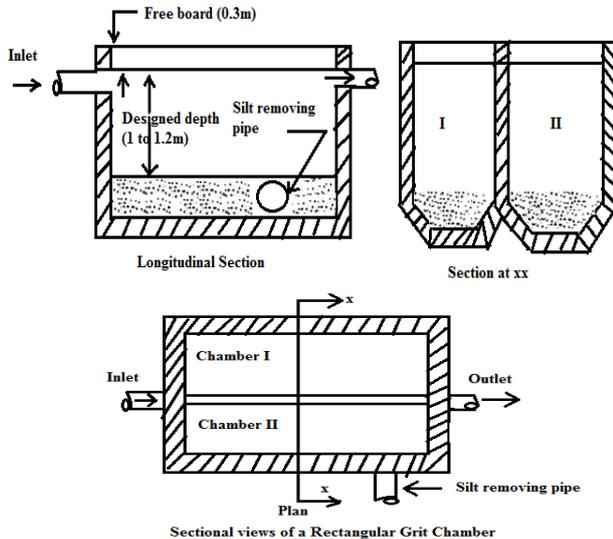
(a) PROPORTIONAL FLOW WEIR

(b) SUTRO WEIR

If proportional used weir is used, rectangular section is provided and if

Parshall flume is used, parabolic channel is produced.

- A Parshall flume can be used both as a discharge measuring device and also a velocity control devices.
- Parshall flume is preferable because head loss is less.
- Velocity control devices are provided at the end of channel.



Sectional views of a Rectangular Grit Chamber

- Sludge of grit chamber is disposed by tutorial or burning or filling ditches by dumping.

6.2.4 DESIGN CRITERIA

- Grit chamber removes particles of size ≥ 0.2 mm
- The specific gravity of the frit is usually in the range of 2.4 to 2.65. but for design adopt ≈ 2.65 .
- For 0.2 mm particle setting velocity = 0.025 m/s
- Surface over flow rate (Q/A) = 2160 $\text{m}^3/\text{m}^2/\text{day}$.
- Stokes law cannot be applied to grit chamber settling because particle size is ≥ 0.2 mm. the settling velocity of discrete particles can be determined using the appropriate equation depending upon the Reynolds number. For this condition, the transition flow

when Re is between 1 and 1000. In this range,

$$C_D \text{ can be approximated by } C_D = \frac{18.5}{(Re)^{0.6}}$$

$$V_s^2 = \frac{4}{3} \frac{(\gamma_s - \gamma_w)d}{C_D \cdot \rho_w}, Re = \frac{V_s d}{\nu}, d = \text{size of}$$

particle ($0.1 \text{ mm} \leq d \leq 1 \text{ mm}$)

Putting the value of C_D in V_s equation, we get

$$V_s = [0.07(G_s - 1)d^{1.6} \nu^{-0.6}]^{0.714} \quad (\text{All data are in SI units})$$

Horizontal velocity of flow is 0.15 – 0.3 m/s (for particle size ≥ 0.2 mm).

- Horizontal critical flow velocity is given by $V_c = K_c \sqrt{g(G_s - 1)d}$ (units are SI units).

Where $K_c = 3$ to 4.5, a value of 4 is usually adopted.

- Detention time is 40 - 60 sec.
- Depth is 1 - 1.5 m.
- Free board is 0.3 m.
- Length of channel is generally increased by 20% as an allowance for inlet and outlet turbulence.
- Loss of head in a grift chamber varies from 6 to 60 cm depending on the device adopted for velocity control.

- $\eta = \frac{V_s}{V_0}$ where, V_s is settling velocity, V_0

is surface overflow rate.

- The settling velocity of grit particles in the transition zone is also calculated by the Hazen's modified formula.

$$V_s = 60.6(G_s - 1)d \frac{3T + 70}{100} \quad (\text{for } d \approx 0.2 \text{ mm})$$

Where d is in cm. ; T is temperature in degree, C and V_s is in cm/sec.

Note: Particle size < 0.1 mm the flow conditions are laminar where viscous forces dominate over inertial forces.

6.2.5 PRIMARY SEDIMENTATION TANK

Sedimentation tanks are designed to remove a part of the organic matter from the sewage effluent coming grit chambers

in a complete treatment the sedimentation tank is carried twice

- i) Once before the biological treatment (i.e. primary sedimentation)
- ii) Once after the biological treatment (i.e. secondary sedimentation)

Setting velocity

$$V_s = \frac{1}{18} g d \frac{(G_s - 1)}{y} \quad \text{For } d < 0.1 \text{ mm}$$

$$V_s = 418 (G_s - 1) d^2 \left(\frac{3T + 70}{100} \right) \quad \text{For } d < 0.1 \text{ mm}$$

$$V_s = 1.3 \sqrt{g d (G_s - 1)} \quad \text{For } d < 0.1 \text{ mm}$$

$$V_s = 418 (G_s - 1) d \left(\frac{3T + 70}{100} \right) \quad \text{For } d \text{ between } 0.1 \text{ to } 1 \text{ mm}$$

Where,

D = diameter of particle in (mm)

T = temperature in (°C)

G_s = specific gravity of particle

V_s = setting velocity in (cm/sec)

Y = kinematic viscosity

6.2.6 HAZES EQUATION FOR TRANSITION ZONE

$$V_s = 60.6 d (G_s - 1) \left(\frac{3T + 70}{100} \right) \quad \text{For } d \text{ between } 0.1 \text{ to } 1 \text{ mm}$$

For inorganic solid $V_s = d(3T + 70)$

For organic solid, $V_s = .012d(3T + 70)$

$$\text{Flow velocity } V = \frac{Q}{BH}$$

From geometric consideration.

$$\frac{V}{V_s} = \frac{L}{H}$$

$$\text{But } V = \frac{Q}{BH} \text{ hence } V_s = \frac{Q}{31}$$

⇒ It shows that all those particles with a setting velocity equal to or greater than Q/BL will settle down and removed

⇒ Setting velocity tanks is also called overflow or surface loading or overflow velocity

- The discharge per unit area $\frac{Q}{BL}$ is an important from for the design type of setting tank

- Normal value of overflow rate ranges between

i) 40 to 50 60 / cm²/day 1650 to 2100 1/hm² - for plain primary sedimentation tank

ii) 50 to 60 Cm²/day - for sedimentation tank using coagulant as-aid

iii) About 25 to 35 Cm/ m²/day - for secondary sedimentation tank

- Smaller particle will also settle down. If over flow rate is reduced.

- Used value of effective depth (i.e. depth excluding both sludge zone) rang between 2.4 to 36 m.

- Detention time for a rectangular tank = $\frac{BLH}{Q}$

- Detention time for circular tank = $\frac{0.1 \frac{1}{4} + 0.785SHd^2}{Q}$

- Width of tank is usually kept about 6 m and not allowed to exceed 7.5 m or so.

- Length of tank is generally not allowed to exceed 4 to 5 time the with

- The flow velocity is generally tank as 0.3 m / minuets

- Displacement efficiency = $\frac{\text{flowing through period}}{\text{detention period}}$

- For tanks without mechanic sludge removal equipment an additional minimum death of above 0.8 to 1.2 m should be provided for storage of settled material and is called sludge zone

6.2.7 SECONDARY TREATMENT THROUGH BIOLOGICAL FILTRATION OF SEWAGE

Method to change sewage

- 1) Filtration
- 2) Activated sludge process
- 3) These process help in changing the instable organic matter into stable forms. All the secondary treatment

process (i.e. filtration as well as activated sludge process) are designed to work on aerobic bacterial decompositions

6.2.8 FILTRATION

Type of filter used in sewage treatment

1) Contact beds: (obsolete these days)

It is a water tight rectangular tank, filled with filtering media consisting of gravel ballast or broken bricks or stones size of media particular may vary between 20 to 40 mm depth of filtering media varies between 1 to 1.8 m.

2) Intermittent sand filtration for biological filtration of sewage (used at small plant)

These are more or less like contact beds with the difference that contacts media here is finer than that in the contact beds and also these is no concrete lining around the filtration media.

3) Trickling filters biological filtration of sewage

- The conventional trickling filtration and their improved forms called high rate
- Trickling filtration are now almost universally adopted for giving secondary treatment to sewage.
- These filters also called percolating filters or sprinkling filters, consist of tanks of causes filtering media over which the sewage is allowed to sprinkle or trickle down by means of spray nozzles or rotary distribution.

4) Miscellaneous type of filter (used under special circumstances)

The sewage influent entering the filter must be given per treatment including screening abed primary sedimentation.

6.2.9 DESIGN OF DRINKING FILTERS

The design of trickling filter primarily involve the design of diameter of the circular filter tank and its depth. Design of rotary distribution and under-drainage system is also involved in the filter design. Design of the filter size is based upon the value of the filter loading. This loading on a filter can be expressed in two ways.

- By quality of sewage applied per unit to surface area of filter per day this is called hydraulic loading rat and expressed in ML/ha/day Value of hydraulic loading for conventional filters may vary between 22 to 44 (normally 28/ml/ha/day). Hydraulic loading can still be increased to about 110 to 330 (normally 220) ML/ ha/ day in the high rate trickling filters
- By the means of B.O.D per unit value of the filtering media per day This called organic loading rate and expressed in kg of BOD per hectare meter of the filter media per day. Value of organic loading for conventional filters may between 900 + 2200 kg of B.O.D per ha.m this organic loading value can be further increased to about....

$$\text{Value of filter} = \frac{\text{Total BOD sewage entering the sewage}}{\text{Organic loading rate}}$$

$$\text{Area of filter bed} = \frac{\text{Total value sewage entering the bed}}{\text{Hydraulic loading rate}}$$

The filter media and depth is designed for average value of flow rotary distributors under-drainage system and other connected pipe lines etc are designed for peak and checked for the average flow.

6.3 TYPES OF TRICKLING FILTERS

- Conventional Trickling filter or ordinary trickling filters or standard or low rate trickling filter:

The effluent obtained from a conventional trickling filter is highly stabilized and nitrified. The BOD is reduced to about 80-90% of the original

value As per national research council of U.S.A

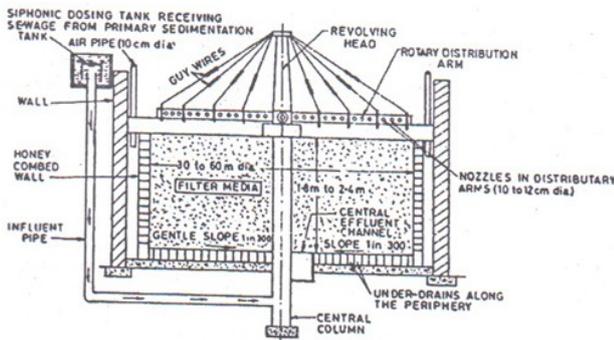
$$n = \frac{100}{1 + 0.0044\sqrt{\mu}}$$

Where,

n = efficiency of filter in terms of % of applied BOD removed

μ = organic loading in kg / ha - m/ day applied to the filter.

- 2) High rate filter or high rate trickling filters. The high rate filter or modern advancement also function on the same lines and are having the same constructional details as standard rate trickling filters but the differences that provision is made in them for recirculation of sewage through the filter



6.3.1 COMPARISON OF CONVENTIONAL AND HIGH RATE TRICKLING FILTER

| | Characteristics | Conventional or standard rate filters | High rate filter |
|----|-----------------------|---|--|
| 1. | Depth of filter media | Varies between 1.6 to 2.4m | Varies between 1.2 to 1.8m |
| 2. | Size of filter media | 25 to 75 mm More | 5 to 60 mm Less |
| | Land required | land area is required as filter loading is less | land area is required as the filter loading is more |
| | Cost of operation | More for treating equal quality of sewage | Less for treating equal quality of sewage |
| | Method of operation | Continues application less flexible required less skilled supervision | Continues application more flexible and more stalled operation is required |

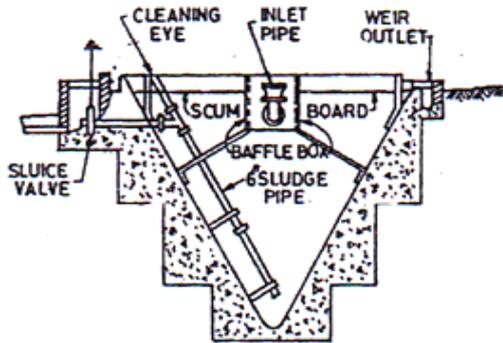
| | | |
|--|--|--|
| Type of effluent produced | Effluent is highly nitrified and stabilized with B.O.D in effluent 20 ppm or so. | Effluent is nitrified up to nitrate stage only and is thus less stable and hence it is of slightly inferior quality BOD in effluents |
| Dosing interval | Generally varies between 3 to 10 minutes Varies loading 20 to 44 m.L per ha/day | 20 ≥ 20 ppm or so |
| Filter loading values i) Hydraulic loading ii) Organic loading | Varies between 900 to 2200 kg of BOD per ha.m of filter media per day | Varies between 110 to 330 mL per hectare per day Varies between 6000 to 18000 of BOD per ha.m of filter media per day |

6.4 SECONDARY SEDIMENTATION

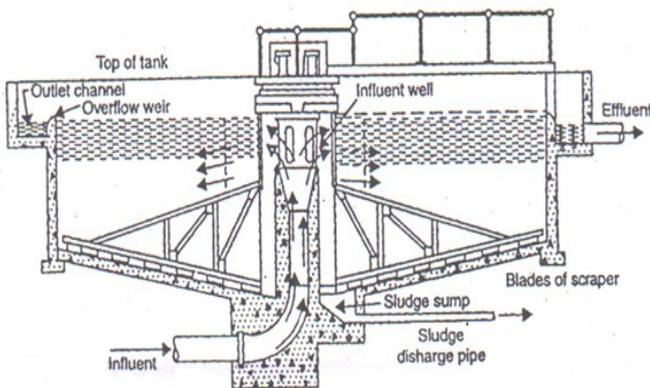
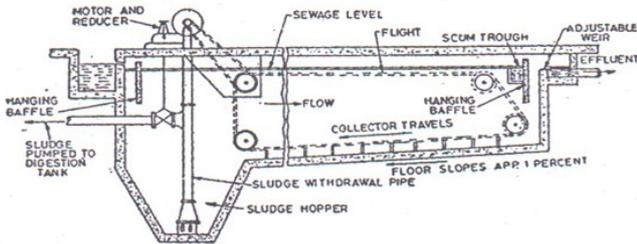
6.4.1 SECOND SETTLING TANKS OR HUMAN TANKS

It was pointed out earlier also filter, in fact, does remove only a very small percentage of the finely divided suspended organic matter present in sewage, while the majority of this organic matter undergoes a change of character, only due to the biological oxidation and nitrification taking place in the filter. Due to the aerobic oxidation and nitrification that takes place in the filter, the organic solids are converted into coagulation suspended mass, which is heavier and bulkier, and would thus settle down, by gravity, if allowed to do so in sedimentation tanks. The effluent of the filter is, therefore, passed through a sedimentation tanks, called secondary clarifier or secondary settling tanks or Humus tanks. A secondary clarifier used for settling the effluents from the filter is similar to a primary settling tank, with a detention period of 1.5 to 2 hours, and over-flow rate per day. Ordinary rectangular tanks with horizontal flow [Rectangular sedimentation tank] or

circular tanks with spiral flow [circular sedimentation tank] may be used. Sometimes, a third type, i.e. hopper bottomed vertical flow type tanks (such as shown in fig) are also used especially for the secondary clarifier.



**Hopper-bottomed conical vertical flow type
Sedimentation tank called Dortmund tank**

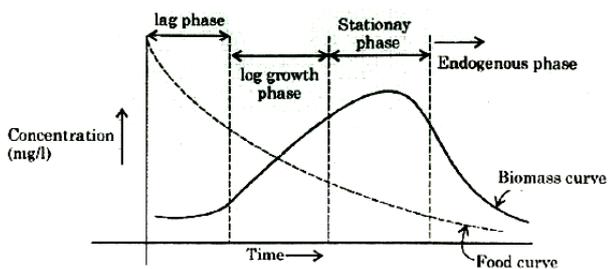


Circular sedimentation tank

7.1 ACTIVATED SLUDGE PROCESS (SUSPENDED GROWTH SYSTEM)

It is an aerobic suspended growth type biological process that uses the active microorganisms kept in suspension in the decompose and stabilize the soluble and particulate (colloidal and suspended) organic matter present in wastewater.

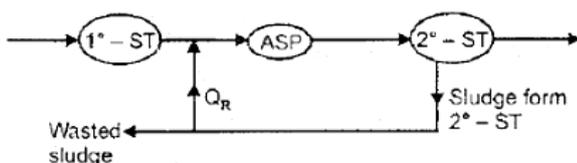
7.2 REACTION KINETICS



If 'S' represents the quantity of soluble food applied and 'X' represents total biomass that is maintained in the reactor to oxidize the incoming organic matter and stabilize them or MLSS (mixed liquor suspended solids). MLSS represents both living and dead bacteria.

Note MLVSS (mixed liquor volatile solid) represent living bacteria only. $MLVSS = 80\% MLSS$.

7.3 ACTIVATED SLUDGE



- The settled sludge in secondary clarifier containing living microorganisms is returned to the reactor to increase the available biomass and speed up the reaction.
- The returned sludge from secondary sedimentation tank is active hence it is called activated sludge.

- ASP is a suspended culture process with sludge return. This process can be :
 - i) completely mix process
 - ii) plug flow process
- These process are aerobic and for this oxygen is supplied from outside.

i) Completely Mix Process

- It is adopted for plant less than 25 MLD.
- It utilizes completely mix flow regime.
- In completely mix process, circular or square tank is used and complete mixing is achieved by mechanical aerator installed at the centre of the tank.
- Complete mixing has a capacity to hold high MLSS level in the aeration tank and hence the volume is reduced.
- It has increased operation stability at shock loading and also increased capacity to treat toxic biodegradable waste like phenol.
- Food/mass ratio (F/M) and oxygen demand is uniform in complexity mix process.

ii) Plug Flow Process

- It is a conventional system and this process has been adopted even for large plant upto 300 MLD.
- Plug flow implies that sewage moves progressively down along the aeration tank essentially unmixed with reset of the tank contents.
- In this case, long narrow channel is used.
- Length is normally taken as $\geq 5 \times$ width.
- The sewage and MLSS (mixed liquor) are left in at the head of tank and withdrawn at the opposite end. In plug flow regime (F/M) ratio and oxygen demand is high at the inlet end of

aeration tank and will then decrease progressively.

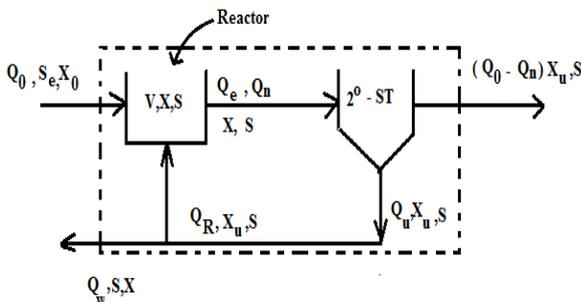
- Plug flow regime lacks operational stability at times of excessive variation in rate of flow and in influent strength.
- The conventional system is always preceded by primary settling.
- BOD removal efficiency is 85 – 92%.

7.3.1 EXTENDED AERATION PROCESS

(Adopted for less than 4 MLD Plant)

- The flow scheme of extended aeration process is completely mix process.
- In this case, **PST** is avoided.
- The process employs low organic loading, long aeration time, high MLSS concentration and low food to mass ratio
- The BOD removal efficiency is high in this case (because F/M is less).
- System works in endogenous phase.
- Because of long detention in aeration tank, the mixed liquor solids undergo considerable endogenous respiration and get well stabilized.
- The excess sludge does not require separate digestion and can be directly dried on sand beds. Oxygen requirement is high in this case.

7.3.2 COMPLETELY MIX PROCESS



Biomass in + Biomass growth = Biomass out

$$\Rightarrow Q_0 X_0 + V \left[\left(\frac{k_0 S}{k_s + S} \right) X - k_d X \right] \text{----- (i)}$$

$$= Q_w X_u + (Q_0 - Q_w) X_e$$

Also, Food in – Food consumed = Food out

$$Q_0 S_0 - V \left[\left(\frac{k_0 S}{k_s + S} \right) \times \frac{X}{Y} \right] \text{----- (ii)}$$

$$= (Q_0 - Q_w) S + Q_w S$$

7.3.3 ASSUMPTIONS

a) Influent and effluent biomass concentration are negligible compared to biomass at other Points (i.e. X_0 and X_e are negligible)

b) All reactions occur in the reactor (Aeration Tank)

From (i) we get

$$XV \left[\left(\frac{k_0 S}{k_s + S} \right) - k_d \right] = Q_w X_u$$

$$\Rightarrow \frac{k_0 S}{k_s + S} = \frac{Q_w X_u}{VX} + k_d$$

From (ii) we get

$$Q_0 S_0 - Q_0 S = \frac{VX}{Y} \times \frac{k_0 S}{k_s + S}$$

$$\Rightarrow \frac{k_0 S}{k_s + S} = \frac{Q_0 Y (S_0 - S)}{VX}$$

$$\therefore \frac{Q_w X_u}{VX} + k_d = \frac{Q_0 Y (S_0 - S)}{VX}$$

$$\frac{Q_w X_u}{VX} = \frac{Q_0 Y (S_0 - S)}{VX} - k_d \text{----- (iii)}$$

7.4 DESIGN PARAMETERS

1. Hydraulic retention time (θ) or time or detention time

$$\theta = \frac{\text{Volume of tank}}{\text{Rate or flow in the Tank excluding recirculation}}$$

$$\Rightarrow \theta = \frac{V}{Q_0}$$

2. Volumetric BOD loading (or organic loading rate)

$$= \frac{\text{Mass of BOD applied}}{\text{Volume of aeration tank}}$$

$$= \frac{Q_0 S_0}{V}$$

3. Specific substrate utilization rate (U)

$$= \frac{Q_0 [S_0 - S]}{VX}$$
 mass of BOD removed per unit mass of biomass in the aeration tank.

If the value of S is small compared to S_0 , which is often the case, U can be also expressed as food applied to biomass ratio (F/M ratio) i.e.

$$F/M \text{ ratio} = \frac{Q_0 S_0}{VX}$$

Lower the food to mass ratio, greater will be the removal of BOD.

4. Sludge age (θ_c)

It is defined as the average time for which a biomass remain in the system. It thus Indicates the residence time of biological solids in the system.

$$\theta_c = \frac{\text{Mass of MLSS in the aeration tank}}{\text{Mass of MLSS leaving the system per day}}$$

$$\theta_c = \frac{VX}{(Q_0 - Q_w)X_e + Q_w X_u}$$

If X_e is neglected, then

$$\theta_c = \frac{VX}{Q_w X_u}$$

From (iii), we get

$$\frac{1}{\theta_c} = UY - k_d$$

$$\text{Also } VX = \frac{YQ_0(S_0 - S)\theta_c}{1 + k_d\theta_c}$$

5. Sludge Volume Index (SVI)

- MLSS concentration in the aeration tank is controlled by sludge recirculation ratio and sludge settleability.
- Sludge recirculation and settleability are determined by SVI.
- SVI indicates the physical state of sludge in the biological aeration system.
- SVI represents the degree of concentration of sludge in the system and hence decides the rate of recycle of

sludge required to maintain desired MLSS and F/M ratio in the aeration tank to achieve the required degree of purification.

- SVI is defined as volume occupied in ml by 1 gm of solid in the mixed liquor after settling for 30 minutes. Its unit is ml/gm.

- Writing balance eq. about aeration tank

$$Q_0 X_0 + Q_R X_u = (Q_0 + Q_R) X$$

$$Q_R (X_u - X) = Q_0 X - Q_0 X_0$$

$$\text{Neglecting } X_0, \frac{Q_R}{Q_0} = \frac{X}{X_u - X}$$

If $\alpha = \text{SVI}$

$$\frac{1}{\alpha} \text{ g/mL} = \frac{10^3 \text{ mg}}{\alpha \times 10^{-3} \text{ l}} = \frac{10^6 \text{ mg}}{\alpha \text{ l}}$$

$$\Rightarrow \frac{Q_R}{Q_0} = \frac{X}{X_u - X} \text{ where } X \text{ is MLSS in tank (mg/l)}$$

$$\text{But, } X_u = \frac{10^6}{\text{SVI}} Z$$

Note: If $\alpha = \text{SVI}$

$$\Rightarrow \frac{1}{\alpha} \text{ m/mL} = \frac{10^3 \text{ mg}}{\alpha 10^{-3} \text{ l}} = \frac{10^6 \text{ mg}}{\alpha \text{ l}} = \frac{10^6}{\text{SVI}}$$

$$\Rightarrow \frac{Q_R}{Q_0} = \frac{X}{\frac{10^6}{\text{SVI}} - X} \text{ - Recirculation Ratio}$$

- Value of SVI should be between 80– 150 (in ml/g). This will ensure that there is sufficient settle ability of sludge.

7.4.1 EXPERIMENT

The standard test, which is performed in the laboratory to compute SVI of an aeration system involves collection of one litre sample of mixed liquor from the aeration tank from near its discharge end in a graduated cylinder. This 1 litre sample of mixed liquor is allowed to settle for 30 minutes and the settled sludge volume (V_{ob}) in ml is recorded as to represent sludge volume. This volume V_{ob} in ml per litre of mixed liquor will represent the quantity of sludge in the liquor in ml/l.

The above sample of mixed liquor, after remaining the settled solids, is further tested in the laboratory for MLSS by the standard procedure adopted for measuring the suspended solids in sewage. Let this concentration of suspended solids in the mixed liquor in mg/l be X_{ob} . Then SVI is given by the equation

$$SVI = \frac{V_{ob} \text{ (ml/mg)}}{X_{ob} \text{ (l/mg)}} = \frac{V_{ob}}{X_{ob}} \text{ ml/mg}$$

$$\text{Or } SVI = \frac{V_{ob}}{X_{ob}} \times 1000 \text{ ml/g}$$

7.4.2 OPERATION

- The most important aspect in the operation of activated sludge plant is to maintain proper food to mass ratio which is achieved by increasing or decreasing MLSS levels in the aeration tank to suit the influent BOD load.
- The MLSS in the aeration tank is regulated by controlling the **rate** or **sludge return** based on SVI determine experimentally.
- The excess sludge is wasted i.e., taken out of the system. The excess sludge is taken to the sludge digestion tank and when to the sand drying bed.
- In case of extended aeration process the wasted sludge is directly taken to the sludge drying bed.
- The excess sludge is wasted to maintain desired MLSS in aeration tank and also to reduce sludge age (θ_c).

7.5 DESIGN OF AERATION TANK

| Process Type | Flow regime | MLSS Mg/l | $\frac{\Delta MLVSS}{MLSS}$ | F/M | HRT (hr.) | θ_c days | Q_w/Q | η | $\frac{Kg O_2 \text{ required}}{Kg \text{ of BOD required}}$ |
|-------------------|----------------|-----------|-----------------------------|----------|-----------|-----------------|----------|--------|--|
| Conventional | Plug Flow | 1500-3000 | 0.8 | 0.3-0.4 | 4-6 | 5-8 | 0.25-0.5 | 85-92% | 0.8 - 1.0 |
| Completely mix | Completely mix | 3000-4000 | 0.8 | 0.3-0.5 | 4-5 | 5-8 | 0.25-0.8 | 85-92% | 0.8 - 1.0 |
| Extended Aeration | Completely mix | 3000-5000 | 0.8 | 0.1-0.18 | 12-24 | 10-15 | 0.5-1.0 | 95-98% | 1.0-1.2 |

- Volume of aeration tank can be calculated from equation

$$VX = \frac{Y \cdot Q_0 (S_0 - S) \theta_c}{1 + k_d \theta_c}$$

By assuming the value of θ_c and X from the table.

- It can also be calculated from

$$F/M = \frac{Q_0 S_0}{VX}$$

By assuming F/M and X from the table.

- Completely mix tank is designed as square or circular whereas plug flow system is designed as long narrow channel.

- Depth controls the aeration efficiency. Depth for plug flow system is adopted between 3- 4.5 m. For plant capacity greater than 50 MLD, 4.5 m depth is economical.

- Width controls mixing efficiency (excessive width will lead to settlement of solid in tank). Width adopted is between 5 -10 m for plug flow system.

- Width by depth ratio is 1.2 to 2.2, length should be greater than 30 m and should not be more than 100 m.

- Horizontal velocity of flow = 1.5 m/min.

- Oxygen required =

$$\frac{Q_0 (S_0 - S)}{f} - 1.42 Q_w \times X_u = \text{biological COD}$$

- COD of wasted sludge

$$\text{Where } f = \frac{BOD_5}{BOD_u} \approx 0.68$$

1.42 is oxygen demand of biomass in gm per gm of sludge wasting.

This formula does not allow for nitrification. It allows only for carbonaceous BOD removal. Extra theoretical oxygen required for nitrification is 4.56 kg of ammonia converted to nitrate.

7.5.1 EXCESS SLUDGE WASTING

- It is done to maintain steady level of MLSS in the track and to maintain

sludge age.

- Excess sludge **quantity will increase** with increasing food to mass ratio and decreases with increasing temperature.
- For domestic sewage excess sludge is 0.35 – 0.5 kg per kg of BOD₅ removal for conventional plant. It is 0.25 – 0.35 kg per kg of BOD₅ removal in extended aeration process having no primary clarifier.

7.5.2 NITRIFICATION

- ASP plant is normally designed for removal of carbonaceous BOD only. However, there may be some nitrification taking place which will consume oxygen supplied and hence reduces dissolved oxygen in aeration tank.
- This problem can be overcome by increasing the sludge wasting rate. (So as to reduce θ_c and hence nitrification will reduce).
- Nitrification can lead to subsequent denitrification ($N_2 \uparrow$) in secondary tank causing sludge rising problem called blanket rising.
- Nitrification is generally not desired but may be required when nitrification and subsequent denitrification is proposed for elimination of nitrogenous matter from the effluent to control eutrophication of lakes.
- In such cases plug flow system has been designed for effluent removal of both carbon and nitrogen.
- Alternatively, a two stage system may be designed with carbonaceous BOD removal in 1st stage and nitrification in 2nd stage.

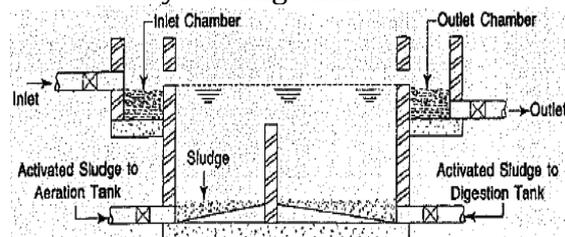
7.5.3 SLUDGE BULKING

- Sludge with poor settling characteristics is termed as bulking sludge.

- Sludge bulking results in poor effluent due to preponderance of excessive suspended solids and also in rapid loss of MLSS from the aeration tank.
- Sludge bulking is due to inadequate air supply resulting in lower pH and septicity. This facilitates the growth of filamentous organisms.
- Filamentous bacteria also from due to low nutrient concentration and its growth is supported by **high sludge age, low F/M ratio** and higher waste temperature.
- This can be reduced by :
 - a) reducing the sludge age.
 - b) chlorination of returned activated sludge.
 - c) addition of nutrient if it less (BOD₅ : N₂ : P ratio recommended = 100 : 5 : 1).

7.6 SECONDARY SEDIMENTATION TANK

- The secondary sedimentation tank is also known as secondary clarifier or secondary settling tank.



Secondary sedimentation tank

- Secondary clarifier for ASP must accomplish two objectives :
 - i) They must produce an effluent sufficiently clarified.
 - ii) They must concentrate the biological solids to minimize the quantity of Sludge that must be handled.
- Secondary sedimentation tank removes **biofloculated solids**.
- It is designed on the basis of :
 - a) Solid loading rate
 - b) Over flow rate (Hydraulic loading rate)

- In SST hindered settling or zone settling occurs because bioflocculated solids are close enough so that their velocity fields overlap causing hindered settling.
- The settling of particles results in significance upward displacement of water.
- The particles maintain their relative positions w.r.t. each other and the whole mass of particles settles as a unit or zone.
- In the hindered settling zone concentration of particles increase from top to bottom leading to thickening of sludge. Such secondary clarifier where zone settling occurs are designed on the basis of solid loading rate and checked for surface overflow rate.

| | Overflow rate (m ³ /m ² /day) | | Solid loading rate (kg/m ² /day) | | Depth (m) | Detention Time (hr) |
|---|---|-------|---|------|-----------|---------------------|
| | Avg. | Peak | Avg. | peak | | |
| 2 ^o ST for TF | 15-25 | 40-50 | 70-120 | 190 | 2.5-3.5 | 1.5-2 |
| 2 ^o ST for ASP excluding extended aeration | 15-35 | 40-50 | 70-120 | 210 | 3.5-4.5 | 1.5-2 |
| 2 ^o ST for extended aeration | 8-15 | 25-35 | 25-120 | 170 | 3.5-4.5 | 1.5-2 |

Note: Detention time in SST is small as otherwise denitrification will occur and N₂ will evolve.

- Surface area adopted should be maximum of the surface area from solid loading rate and overflow rate.

$$\text{Area (Avg.)} = \frac{Q_0}{\text{Over flow rate}}$$

(from overflow rate criteria)

$$\text{Area} = \frac{(Q_0 + Q_R) X}{\text{Solid loading rate}}, X = \text{MLSS of}$$

aeration tank.

In Trickling filter (Q₀ + Q_R) X should be replaced by amount of bioflocs added to the SST from TF.

- The value of surface area so obtained is checked for peak conditions also

because under peak conditions efficiency may reduce (peaking factor = $\frac{Q_{\max}}{Q_{\text{av}}}$).

- The suspended solid in 2^o – ST are light in weight and are thus markedly influenced by currents.
- Thus, in SST considerable length of overflow weir is desirable to reduce the velocity, hence check for weir overflow rate should also be done.
- Weir overflow rate should be 185 m³/m/day for SST with ASP i.e. discharge per unit perimeter length should be 185 m³/m/ day for SST with ASP.
- Weir overflow rate for SST with trickling filter should be 125 m³/m/day.

7.7 SLUDGE DIGESTION

- Waste water sludge is a considerable hazard to environment and must be rendered inert prior to disposal. The sludge from PST is called raw sludge or primary sludge. Raw sludge is more objectionable. It contains about 95% moisture content. Sludge of SST contains 96-98% moisture. Sludge from PST has excess organic matter and sludge from SST have excess biomass.
- The sludge digestion serves both to reduce the volume of thickened sludge still further and to render the remaining solids inert and relatively pathogen free.
- This goal can be achieved aerobically or anaerobically.

7.7.1 AEROBIC DIGESTION

- It is adopted only for biological sludge (2^o- sludge) that does not contain primary sludge.

- It is just an extension of **extended aeration process**.
- In aerobic digestion as there is scarcity of food, endogenous respiration will start.
- The digested sludge consists of cell walls, and other cell fragments. This process is energy consumptive.
- The sludge dewateres poorly.

7.7.2 ANAEROBIC DIGESTION

- It is carried out primary sludge because this sludge contains large amount of readily available organics that can induce rapid growth of biomass if treated aerobically.
- The anaerobic process produces lesser biomass and also the primary function of anaerobic digester is to convert as much of sludge as possible to liquids and gases while producing little biomass.
- The waste water contains wide variety of organics and hence requires wide variety of organisms also.
- In anaerobic process the organisms are broadly classified are as :
 - a) acid formers and
 - b) methane formers.
- **Acid Formers:** They consist of facultative and anaerobic bacteria and organisms which solublize the organic acids through hydrolysis. The soluble end products are then fermented to acids and alcohols of lower molecular weight.
- **Methane former :** They are strictly anaerobic and convert acids and alcohol along with hydrogen and carbon dioxide to methane. Methane formers act in the pH range of 6.5 – 7.5 and they are very delicate. A shock loading can be disastrous to such anaerobic bacteria. Acid former respond quickly to food supply and hence acid increases

quickly. The methane formers do not respond so quickly and hence pH may reduce. As pH level falls down below: **pH tolerance level”** of the methane former, methane formation ceases and the pH may fall to even toxic level. To control this lime is added.

7.7.3 MERITS AND DEMERITS OF ANAEROBIC DIGESTION Merits

1. Recovery of energy in the form of methane.
2. Anaerobically digested sludge contains nutrients and organic matter that can improve the fertility of soil.
3. Pathogens in the sludge die off during relatively long detention period.

Demerits

1. Close process control is required to prevent upsets.
2. Supernatant liquid from an anaerobic digester have high O₂- demand.

Note Supernatant has BOD apox. 1500 mg/l and high concentration of nitrogen in suspended solid.

$$V(100 - p) = V_1(100 - p_1)$$

Where,

V = volume of sludge at moisture content p

V₁ = volume of sludge at moisture content p₁

7.8 SLUDGE DIGESTION PROCESS

- When sludge is digested anaerobically the volume of original sludge is reduced to apox. $\frac{1}{3}$ of the original value. The sludge gets broken into
 - a) digested sludge
 - b) supernatant liquor
 - c) gases of decomposition
- Of the total solid originally present 70% are volatile and remains 30% are fixed (inorganic solids).
- Volatile solids are measured by an equipment called muffle furnace.

- Of the total volatile solids approx. 65% are reduced to gases in digestion tank.
- The gases produced = $0.9 \text{ m}^3/\text{kg}$ of volatile solids reduced = $0.6 \text{ m}^3/\text{kg}$ of volatile solid present.
- Of the total gases produced 65% are methane and 30% are CO_2 and remaining are other gases like H_2S , N_2 etc.
- Heat content of methane is 8600 kcal/m^3 .
- Supernatant liquid has a high BOD of $1500\text{-}3000 \text{ mg/l}$. hence it should be retreated along with the raw sewage.

Note Volatile solids are measured by an equipment called muffle furnace.

7.9 STAGES IN SLUDGES DIGESTION PROCESS

- Hydrolysis
- Fermentation
- Methane formation (Methanogenesis)

Hydrolysis

It is the 1st step for most of the fermentation process in which **particulate material is converted to soluble compounds**. That can be hydrolyzed further to simple monomers which are used by bacteria to perform fermentation. In this stage, complex organic matter like proteins, cellulose and lipids are converted by extra cellular enzymes into simple soluble organic matters.

Fermentation (Acid genesis)

In this stage, soluble organic matter is converted by acid formers like acetogenic bacteria into acetic acid, hydrogen and CO_2 and other lower molecular wt organic acids.

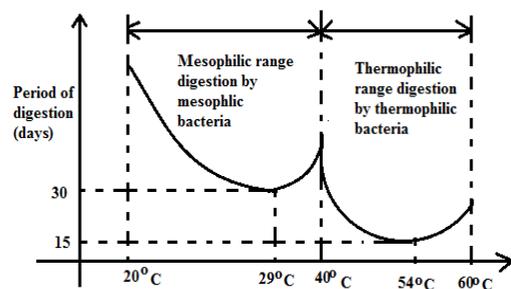
Methane Formation (Methanogenesis)

In this stage two group of methane forming bacteria (strictly anaerobic) are active

- Aceticlastic methanogens – split acetic acid into CH_4 and CO_2 .
- Hydrogen-utilizing bacteria – converts hydrogen and CO_2 into CH_4 .

7.10 FACTORS AFFECTING SLUDGE DIGESTION AND THEIR CONTROL

- Temperature
- pH value
- Seeding with digested sludge
- Mixing and Steering of raw sludge with digested sludge
- Nuisance organism



a) Temperature

- In mesophilic range ($20 - 40^\circ\text{C}$), mesophilic bacteria acts on the sewage and the most effluence temperature of this range is 29°C .
- In thermophilic range ($40 - 60^\circ\text{C}$), thermophilic bacteria acts on the sewage and the most optimum temperature of this zone is 54°C .
- Digestion is generally not done in thermophilic range because of huge offensive odour and operational difficulties. Hence the most efficient temperature during sewage digestion is 29° & duration is 30 days respectively.

b) pH

- Lower pH value suppresses methane formation.
- pH decreases due to overdosing of raw sewage, over withdrawal of digested sludge and by sudden admission of industrial waste.
- Remedy is to add hydrated lime.

c) Seeding with Digested Sludge

It helps in achieving quick balance condition.

d) Mixing and Steering of Raw Sludge

- Excess steering is not desired as it will kill bacteria but steering helps in even distribution of incoming sludge.
- It breaks and reduces scum.
- It helps in increasing the production of gases.

Note: When steering is not done, mixing takes place due to rising gas bubbles.

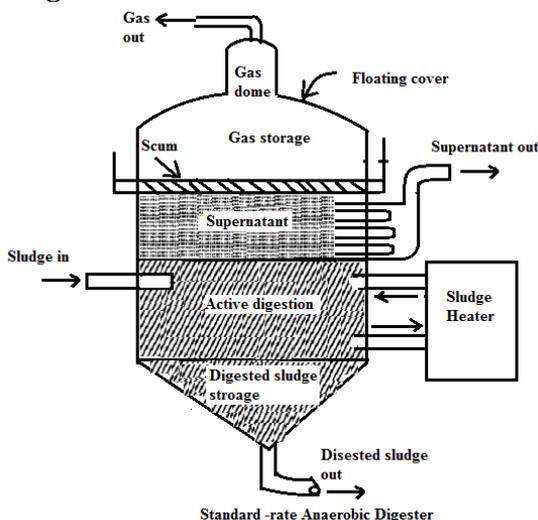
e) Nuisance Organisms

Nuisance organism in anaerobic operations are sulphate-reducing bacteria. When sufficient amount of sulphate is present, these organisms reduce sulphate to sulphide which is toxic to methane forming bacteria. **Remedy** is to add iron to precipitate iron sulphide.

7.11 REACTOR FOR ANASEROBIC DIGESTION

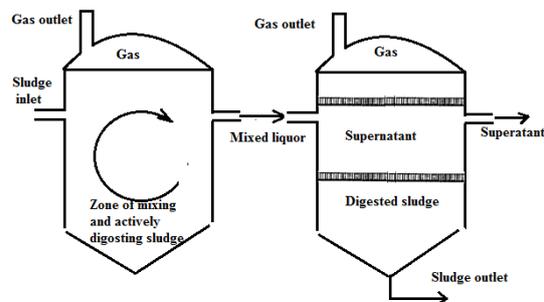
- Standard rate
- High rate

- The reactors consists of close tank with air tight covers.



Standard – rate Anaerobic Digester

- For plant of capacity approval up to 4 MLD, standard rate digester is used.
- The conical bottom facilities sludge withdrawal and floating cover accommodate volume changes due to sludge addition and withdraw and also gas storage.
- The sludge is fed into digester intermittently and supernatant liquor is withdrawn and returned to primary treatment because it has huge suspended solid.
- The digested sludge is taken to sludge drying bed.
- Bubbles of sewage gas provides some degree of mixing.
- If the capacity of treatment plant is more than 4 MLD, high rate digesters are used.
- High rate digesters requires less volume than single stage digesters.



- In 1st range, volume of sludge remains the same as no dewatering occurs but the solid content is charged.
- In 2nd stage, completely mixed sludge from 1st stage is taken and dewatering occurs in this stage, Influent in this stage is super saturated with gases which is released in this stage.
- Complete mixing in 1st stage creates homogeneous environment throughout the digester and raw sludge is quickly brought in contact with microorganisms. Hence the rate of digestion increases.
- In any toxic substance comes with the sludge it is evenly distributed

throughout the 1st stage tank and hence its effect is reduced.

- The raw sludge if pre thickened, will lead to reduction in the volume of sludge and hence energy required for mixing will be reduced.
- But thickening should not lead to **solid concentration greater than 6%** in raw sludge as otherwise the viscosity increases and mixing becomes difficult. This may lead to increase in the toxicity of sludge.
- The combined volume of 1st and 2nd stage tank will be less than the standard rate tank.

7.12 DESIGN (STANDARD RATE DIGESTOR)

- Diameter of tank is normally 6 – 38 m
- Depth of tank is approximately 6 -12 m
- Lower slope is 1 : 1 to 1 : 3.
- Dia/depth = 1.5 – 4.
- Volume of digester is calculated as follows :

$$V = \left[V_1 - \frac{2}{3}(V_1 - V_2) \right] t$$

V = volume of digester

V₁ = volume of raw sludge added per day

V₂ = volume of digested sludge withdrawn per day. It may be taken equal to volume of digested sludge produced per day t = digestion period.

- Digestion period = 30 days (Most optimum duration for mesophilic range).

If during flooding, it is not possible to withdraw digested sludge because the sludge drying bed will be flooded, storage is provided to keep the digested sludge during the flooding monsoon period. Hence volume of tank will be

$$V = \left[V_1 - \frac{2}{3}(V_1 - V_2) \right] t + V_2 T$$

T = Monsoon period.

- The above formula for volume of tank is calculated with the assumption that volume changes in digestion tank takes place parabolically.

- If volume changes are assumed to take place linearly

$$V = \left(\frac{V_1 - V_2}{2} \right) t$$

And if monsoon storage is also taken into account then

$$V = \left(\frac{V_1 - V_2}{2} \right) t + V_2 T$$

Note: All units of treatment are kept above HFL of river expect sludge drying bed. Hence during flooding only sludge drying bed will be flooded, and other units will be operational.

7.13 EFFLUENT DISPOSAL

The proper disposal of treatment plant effluent or reuse requirement is an essential part of planning and designing waste water treatment facilities.

7.13.1 NATURAL EVAPORATION

- Depending upon the climatic conditions large impoundments may be necessary
- This method is particularly beneficial where recovery of residues is desirable such as for disposal of brains

7.13.2 GROUND WATER RECHARGE

Method for groundwater recharge include rapid infiltration by effluent application or impoundment, intermittent, percolation, and direct injection.

- In all cases the risk for groundwater pollution exit.
- Further more, direct injection implies high cost of treating effluent and injection facilities

7.13.3 IRRIGATION

- Irrigation has been practice primarily as a suitable for scarce natural water or sparse rainfall in arid areas.
- In most cases food chain crops (i.e Crops consumed by humans) may not be irrigated by effluents.
- However, field crops such as cotton, sugar feeds, and crops for seed production are grown with wastewater effluent
- Wastewater effluent has been used for watering parks. Golf courses and highway medians.

7.13.4 RECREATIONAL LAKES

- The effluent from the secondary treatment facility is stored in a lagoon for approximately 30 days.
- The effluent from the lagoon is chlorinated and then percolated through area of sand and gravel, through which it travels for approximately 0.5 km and is collected in an interceptor trench.
- It is discharge into series of lakes used for swimming, floating and fishing.

7.13.5 AQUACULTURE

- Aquaculture or the production of aquatic organism (Both Flora and Fauna) has been practiced for centuries primarily for production of food, fiber and fertilizers.
- Lagoons are used for aquaculture all through artificial and natural wetlands are also being considered.
- However, the uncontrolled spread of water hiacinths is itself a great concern because the flora can clog water way and rain water bodies.

7.13.6 MUNICIPAL USES

- Technology is now available to treat wastewater to the extent that it will meet drinking water quality standards.

- However direct reuse of treated wastewater is practicable only on an emergency basis.
- Many natural bodies of water then are used for municipal water supply are also used for effluent disposal which is done to supplement the natural water resources by using the effluent many times before it finally to the sea.

7.13.7 INDUSTRIAL USES

- Effluent has been successfully used as a cooling water or boiler feed water.
- Deciding factors for effluent reuse by the industry include
 1. Availability of natural water,
 2. Quality and Quantity of effluent and cost of processing,
 3. Pumping and transport cost of effluent and
 4. Industrial process water that does not involve public health consideration.

7.13.8 DISCHARGE INTO NATURAL WATER

Discharge into natural waters is the most common disposal practice. The self-purification or assimilative capacity of natural waters is thus utilize to provide the remaining treatment Variation of sludge

$$\text{volume with water content } v = v_1 \left[\frac{100-p_1}{100-p} \right]$$

v = Initial volume

v_1 = Final volume

p_1 = Initial moisture content (%)

p = Final moisture content (%)

8

WASTE WATER TREATMENT

8.1 TREATMENT OF DOMESTIC WASTE WATER

1. Equalization
2. Neutralization
3. Physical treatment
4. Chemical treatment
5. Biological treatment

1. Equalization: Equalization consists of holding the waste water for some predetermined time in a continuously mixed tanks, to produce uniform waste water.

2. Neutralization: Neutralization means neutralizing the excessive acidity or alkalinity of the particular waste water by adding alkali or acids, respectively to the waste water. This may be achieved either in equalization tank where possible or a separate neutralization tank may be used.

3. Physical treatment: Physical treatment consists of separating the suspended inorganic matter by physical like sedimentation and floatation.

i) **Sedimentation:** Sedimentation is employed to separate the heavier settleable solids and hence sedimentation tank may be provided only when the waste water contains a high percentage of such heavy inorganic solids.

ii) **Floatation:** Floatation consists of creation of the air bubbles in the waste tank, by introducing of air into the tank from the bottom. The rising air bubble attach themselves to the bottom suspended particles increasing their buoyancy and removed by skimming.

8.2 CHEMICAL TREATMENT

Chemical Treatment is often necessary before the biological treatment.

The chemical treatment is used to remove the dissolved organic matter from the waste water and may consists one or more of the following process.

- i) Reverse osmosis or hyper filtration
- ii) Electrodialysis
- iii) Chemical Oxidation
- iv) Chemical Coagulation or chemical precipitation
- v) Adsorption
- vi) Deionization
- vii) Thermal reduction and
- viii) Air stripping

8.2.1 REVERSE OSMOSIS

In reverse osmosis treatment process the waste water containing dissolved salts are filtered through semi permeable membrane at a pressure higher than the osmosis pressure. Such treatments required pre-treatments like

- i) Activated Carbon adsorption or
- ii) Chemical precipitation followed by same kind of filtration

8.2.2 ELECTRODIALYSIS

In electrodialysis treatment process dissolved salts from waste water are separated by passing an electric current through the waste water tank. Installed with long exchanger members. This treatment process also requires some pretreatment as is required in reverse osmosis process.

8.2.3 CHEMICAL OXIDATION

In chemical oxidation chemical to reduce substance like ammonia and ozone are used to reduce substance like ammonia and cyanide etc from the waste water in order to reduce BOD load on biological treatment.

8.2.4 CHEMICAL COAGULATION

Chemical coagulation is adopted in treating raw water supplies and helps in sedimentation of un-settleable micro and colloidal impurities. Which get absorbed in the gelatinous flocs. Formed by the chemical reaction between the coagulated and alkaline present in raw water.

8.2.5 ADSORPTION

Adsorption is generally used to remove non-biodegradable organics (like synthetic detergents), colour and odour from the waste water. The process involves passing the pre-treated waste water through the beds of activated carbon, as discussed.

8.2.6 DEIONIZATION

De-ionization involves a similar passage of waste water through the beds of synthetic ion exchange resins, like organic cyanide, which may be present in certain specific industrial waste water.

8.2.7 THERMAL REDUCTION

Thermal reduces required burning and consequent oxidation of some toxic and refractive substance like organic cyanide, which may be present in certain specific industrial waste water.

8.2.8 AIR-STRIPPING

In air-stripping the liquid waste is powered down through a packed tower, equipped with an air flow at the bottom this method is a modification of aeration process used for removal of gases from the waste water.

- It is necessary when they contain large quantities of biodegradable masses.
- $\frac{BOD}{COD} > 0.6$, the waste water are biologically treatable without acclimations.

- $\frac{BOD}{COD} < 0.6$ and 0.3 the acclimatization is needed for biological treatment.
- $\frac{BOD}{COD} < 0.3$, biological treatment is not necessary.

8.2.9 ACCLIMATIZATION

It consists of gradual exposure of waste water in increasing concentration to the seed or initial micro-biological under a controlled condition.

- For balance growth of micro-organism in a biological treatment reactor, the ratio of BOD : nitrogen : phosphorous be 100:5:1 for aerobic system and 100:2:0.5 for anaerobic system.

8.3 SLUDGE DISPOSAL

Reuse: All solid and semi-solid waste of a community except human excrete and sullage is classified under the general term reuse, and include garbage, ash, rubbish dust etc.

- Garbage:** It includes starts of putrescible organic wastes obtained from kitchen, hotels, restaurant etc. Vegetable peeling. Foot articles fruits peeling etc, are thus included in this term garbage normally weights 700 to 850 kg/m².
- Rubbish:** Rubbish including all non-putrescible waste except ashes it thus include all combustible and non-combustible wastes such as rags, paper pieces broken piece of glass and furniture cardboard, broken crockery etc. Rubbish is lighter and normally weights between 50 to 400 kg/m. The usual weight of refuse (mixture of all type) generally varies between 300 to 600 kg/m³. In an average modern city each citizen produced about 0.3 to 0.8 kg of solid domestic waste per day.

Calorific Value ≈ 1200~1600 kcal/kg

(For Indian Refused)

| Reuse | Indian City | U.S.A City |
|--------------------|-------------------|-----------------------------|
| Garbage | 50% | 20% |
| Rubbish | 10% | 50% |
| Ashes | 15% | 15% |
| Dust silt and sand | 25% | 15% |
| Unit wt | 400-600 kg/m | 100-250 kg / m ³ |
| Calorific value | 1200-1600 kcal/kg | 3500 |

8.3.1 DISPOSAL OF REFUSE

Disposal can be done by various methods

- i) Sanitary land fillings
- ii) Burning or incineration
- iii) Bageing it out into sea
- iv) Pulverization
- v) Composing i.e. by digestion by bacterial agency

i) Sanitary Land Filling

- Refused is dumped into the low lying area under an engineering operation.
- Reuse is dumped into layers of 1.5 m or so each layer is covered by good earth of atleast 20 cm thickness. So that the refuse is not directly exposed. Each layer structure is called 'Cell'.
- Each layer should be left out for atleast 7 days and should be compacted before filling 2nd layer.
- Insecticides like DDT, creosote, creosol etc. should also be sprayed on the layers to prevent breeding of mosquitoes and flies.
- A final cover of about 1 m of earth is laid and compacted at the top of filled up land.
- The land filling operation is essentially a biological method of waste treatment since the waste is stabilized under aerobic and anaerobic processes.

The Entire Period of Reuse Stabilization can be Divided into 5 Distinct Phase

- i) **During 1st phase:** aerobic bacteria and fungi, deplete the available

oxygen to effect oxidation of organic matter, as a result temperature increased.

- ii) **During 2nd phase:** Anaerobic and facultative bacteria develop to decompose the organic matter and H₂ and CO₂ gases are thus evolved.
- iii) **During 3rd stage:** Metharorganic bacteria develop to cause evolution of methane gas.
- iv) **In the 4th phase:** The metharogenic activity gets stabilized.
- v) **In the 5th stage:** The metharogfenic activity subsides matter and ultimately system returns to aerobic conditions within land fill. For better biological decomposition, the moisture content < 60%. The reuse gets stabilized generally within period of 2 to 12 months and settles down by 20-40% of its original height.

8.3.2 PROBLEM/DISADVANTAGE

- **Leachate**
- **Foul Gases**

ii) Incineration and Thermal Pyrolysis

- Burning of refuse at high temperature in furnace, it is widely used in U.S.A but due to a low calorific value of re-use, it is not used in India only combustible matter are burnt, the left over ashes and clikkers along with non-recycled incombustible materials may be as much as 10-25% which has to be disposal by some other methods.
- The heat produced during burning of reuse is used in the stream power for running turbines to generate electricity.
 - Large sized incinerators are called destructors.
 - The minimum temperature in the combustion chamber should be sufficient (> 670%) so as to incinerate all organic matter and oridises foul smelling gases.

- If steam is to be generated a temperature of about 1000°C is required to be produced in combustion chamber.

8.3.3 DISADVANTAGES

- Costly
- Smoke, odour and ash nuisance

8.3.4 DISPOSAL OF REFUSE BY BARGEING IT OUT INTO THE SEA

- Throwing refuse into the sea at reasonable distance from the coast (say 16 to 20 kms).
- The sea depth at disposal point should not be less than 30 m or 50 m.

8.3.5 DISADVANTAGE

- Bulky materials float and tend to the shores.
- Ships and streamers are needed so not generally used.

8.3.6 DISPOSAL OF REFUSE BY PULVERIZATION

Refuse is pulverization in grinding machine so as to reduce its volume and to change its physical character. The grinder or pulverized refuse becomes practically odourless and unattractive to the insects. It has to be further disposed of by filling in trenches or digested in open windows or closed digestion.

8.3.7 DISPOSAL OF REFUSE BY COMPOSITING

Compositing is a biological method of decomposing solids waste, their decomposition can be either under aerobic or anaerobic conditions.

- Final end product is a manure called compost or humus.
- Sticky speaking compositing is the aerobic process because it involves

regular turning either manually or mechanically so as to ensure sufficient supply of oxygen. Initially process starts with mesophilic bacteria and then temperature rises to 45°C and at this point after 3 weeks the compost is stabilized and this is shown by appreciable fall in temperature, the final

In India: Generally two methods are adopted for compositing

1. Indore process (Used in rural Area)
2. Bangalore Process

9

SOLID WASTE MANAGEMENT

9.1 INTRODUCTION

- Solid wastes are the total wastes arising from human and animal activities that are normally solid and hence are useless or unwanted.
- It encompasses the heterogeneous mass of throw away from houses of commercial centers as well as the nearby homogeneous accumulation of a single industrial activity.
- Refuse represents the dry wastes or solid wastes of the society.
- The term 'refuse' is often used interchangeability with term solid wastes.
- The density of Indian refuse is generally higher than of the developed countries and hence the Indian refuse can be carried efficiently and economically by mechanical transport (carrying more wt. for the same volume).
- The calorific value of Indian refuse is much smaller, and its moisture content is high.

9.2 TYPES OF SOLID WASTES

Major categories of solid waste generation are :

- i) Municipal wastes
- ii) Industrial wastes
- iii) Hazardous wastes.

9.2.1 MUNICIPAL WASTES

- Solids wastes generated from different zones of the city differs in characteristics. These solid wastes comprise refuse, ordinary refuse (includes garbage & rubbish) and trash.
- Refuse, refers to nonhazardous solid waste from the community requiring

collection and transporting to processing/disposal site.

- Garbage comprises items that are highly decomposable (putrescible) food, waste vegetables and meat scraps.
- Rubbish contains mostly dry, non decomposable (nonputrescible) material – glass, rubber, tin cans, also, or combustible material – paper, textiles, wooden articles, etc.
- Hence, community refuse can be referred to as municipal solid waste (MSW).

9.2.2 INDUSTRIAL WASTES

- Industrial wastes are generated from the industrial activities or manufacturing processes.
- All the three types of wastes, solid, liquid and gaseous are generated.
- Industrial wastes can be categorized as non-hazardous and hazardous. It is well known hazardous wastes have a potential for every deleterious impact on environment and life in general.
- Some of the common industries which generate solid waste along other wastes on a large scale are :
 - i) Paper and pulp
 - ii) Metallurgical industries
 - iii) Pesticides/Insecticides
 - iv) Fertilizers
 - v) Plastics
 - vi) Refineries

9.2.3 HAZARDOUS WASTES

- Hazardous substance can be defined as anything which because of its quantity, concentration or characteristics may contribute to increased mortality, illness or hazard to human health and

environment if not properly stored and transported or disposed off.

- As per the Resource Conservation and Recovery Act (RCRA), USA, the hazardous waste is one which possesses any one of the four characteristics, such as, ignitability, corrosivity, reactivity or toxicity.
- Hazardous differ in form as well as behavior from ordinary solid wastes. They generally are produced in liquid form; however, they can also occur as solids, sludge, or gases. They are infectious and radioactive.
- Some of the common industries which generate hazardous waste are:
 - i) Ferrous, non-ferrous industries
 - ii) Cement industries
 - iii) Petroleum industries
 - vi) Chemical industries

9.3 CLASSIFICATION OF REFUSE

9.3.1 BASED ON THE TYPE OF WASTES

a) Garbages

It includes all sort of putrescible organic wastes, obtained from kitchens, hotels, restaurants like waste food articles, vegetable peelings, fruit peelings, etc. these wastes are organic in nature, and hence, likely to decompose quickly, producing foul odours and health hazards. They may also result in breeding of flies, mosquitoes, insects, etc. Hence, garbage must be disposed off, properly and quickly. When it is scientifically processed and composted then we may obtain some valuable products like grease, fertilizer, etc. from garbage. The density of garbage usually varies between 450 to 900 kg/m³.

b) Ashes

Ashes are the incombustible waste products from hearths and furnace, and houses or industries. The density of

ashes generally vary between 700 to 850 kg/m³.

c) Rubbish

Rubbish includes all non-putrescible wastes except ashes. All combustible wastes, such as rags, paper pieces, broken pieces of glass and furniture, card-boards, broken crockery comes under. Rubbish is lighter, and normally has a density varying between 50 to 400 kg/m³.

9.3.2 BASED ON THE SOURCES

Refuse may also be classified, depending on its source, as:

- i) House refuse
- ii) Street refuse
- iii) Trade refuse

These terms are self-explanatory.

Note: The usual density of refuse (mixture of all types of dry wastes) generally varies between 300 to 600 kg/m³.

9.4 ON SITE HANDLING, STORAGE, AND PROCESSING

The handling, storage, and processing of solid wastes at the source before they are collected are the functional elements in a solid-waste management system.

On-site handling refers to the activities associated with the handling of solid wastes until they are placed in the containers used for their storage before collection. Depending on the type of collection service, handling may also be required to move loaded containers to the collection point and to return the empty containers to the point where they are stored between collections.

Factors considered in the **on-site storage** of solid wastes include:

- i) the type of container to be used,
- ii) the container location,
- iii) public health and aesthetics
- iv) the collection methods to be used.

On-site processing methods are used to recover usable materials from solid wastes, to reduce the volume, or to alter the physical form. The most common on-site processing operations include manual sorting, compaction, and incineration.

9.4.1 PROCESSING TECHNIQUES

Processing techniques are used in solid waste management systems to

- i) improve the efficiency of solid-waste disposal systems
- ii) to recover resources (usable materials)
- iii) to prepare materials for the recovery of conversion products and energy.

Important processing techniques used routinely in municipal solid-waste systems include; compaction, thermal volume reduction (incineration), and manual separation of waste components.

i) **Mechanical volume reduction**

It is the most important factor in the development and operation of solid-waste management systems. Vehicles equipped with compaction mechanisms are used for the collection of most municipal solid wastes. Wastes are compacted to increase the useful life of landfills.

ii) **Thermal volume reduction**

The volume of municipal wastes can be reduced by more than 90 percent by incineration. Incineration was quite common in the past, however, with more restrictive air-pollution control requirements, only a limited number of municipal incinerators are currently in operation.

iii) **Manual component separation**

The manual separation of solids waste components can be accomplished at the source where solid wastes are generated, at a transfer station, at a centralized processing station, or at the disposal site. Manual sorting at the source of generation is the most positive way to achieve the recovery and reuse of materials. The number and

types of components salvaged or sorted (e.g., cardboard and high quality paper, metals, and wood) depend on the location, the opportunities for recycling, and the resale market.

9.5 METHODS OF SOLID WASTE COLLECTION

9.5.1 COLLECTION, REMOVAL AND CARRIAGE OF REFUSE

- Regular collection and transport of solid waste are most important operations in any efficient solid waste management which costs about 80% of the total cost of solid waste management.
- In India, refuse is generally collected in individual houses in small containers and from there it is collected by sweepers in small hand driven lorries/carts and then dumped into the layout of street and density of population.
- The capacity of the bins may vary from 100 to 500 liters depending on the quantity of zone wise waste generation.
- In case of large quantity of putrescible garbage from residential area, it will be appropriate to follow on-site storage.
- The waste from the community storage bins is collected by transport vehicles daily for final disposal or treatment. Combined collection of garbage and rubbish is more economical. If materials are to be recycled, home owners can practice source separation i.e. into paper, glass etc.
- Methods adopted in India are not satisfactory and needs further improvements and changes.

9.5.2 POINTS TO BE TAKEN CARE OF DURING SOLID WASTE COLLECTION

- Spreading or scattering of refuse while dumping in the community storage bins

by the house sweepers and street scavengers should be avoided.

- Transport vehicles should be cleaned periodically, thus avoiding decomposition and evolution of health hazard causing obnoxious gases.
- Community storage bins as well as transport vehicles should have cover/lid thus reducing incidence of rodents, insect infestation and unpleasant sights at the site.
- Transport vehicles should visit the houses, twice a day, once in the morning and once in the evening to collect household refuse and street sweepings.
- Transport vehicles should be strong, durable and water tight and made of stainless steel with smooth interior having round corners and edges for facility of cleaning
- Transport vehicle should have a low loading line (about 1.5 m), so that minimum of time and effort is required in filling them.
- Mechanical devices should be installed in these vehicles for lifting the body to the sides or back or for pushing the refuse out in order to empty it quickly and easily.
- An optimum collection route, particularly for large and densely populated area should be selected in order to optimize the collection system

9.6 DISPOSAL OF SOLID WASTE

Disposal on or inside the earth is the only feasible method for the long term handling of the following

- i) solid wastes that are collected and are of no further use,
- ii) residual matter remaining after solid wastes have been processed,
- iii) residual matter remaining after the recovery of conversion products and/or energy has been accomplished.

Note: Land filling is the method of disposal used most commonly for municipal wastes; land farming and deep-well injection have been used for industrial wastes. Although incineration is often considered a disposal method, it is, in reality, a processing method.

9.6.1 POINTS TO BE KEPT IN MIND DURING DISPOSAL OF SOLID WASTE

- Appropriate method of disposal of solid waste should be chosen among the methods discussed in the section ahead in order to satisfy the present as well future requirements.
- It should not create environmental pollution and should result in recovery of material as well as energy. Most commonly employed methods for solid waste disposal, practiced all over the world are
 - i) Open dumping
 - ii) Sanitary land fill
 - iii) Compositing
 - iv) Shredding (or Pulverisation)
 - v) Incineration
 - vi) Pyrolysis

9.7 DISPOSAL OF REFUSE BY OPEN DUMPING

- Oldest method of disposing SW.
- Very simple method and commonly adopted in our country.
- SW collected from the city zone is dumped in low lying areas located far off from the city.
- Not an eco-friendly method and thus results in contamination of environment.
- This method is highly unacceptable as it gives unsightly nuisances, obnoxious smell and is a breeding place for flies and mosquitoes.
- The method is still in practice in semi-urban and rural areas.

9.8 DISPOSAL OF REFUSE BY SANITARY LAND FILLING

Important aspects in the implementation of sanitary landfills include :

- 1) site selection,
 - 2) landfilling methods and operations,
 - 3) occurrence of gases and leachate in landfills,
 - 4) movement and control of landfill gases and leachate.
- In this method, refuse is carried and dumped into low lying areas under an engineered operation, designed and operated according to acceptable standards.
 - It involves a controlled disposal of SW on or in the upper layers of the earth's surface.
 - The refuse is dumped and compacted in layers of 0.3 to 0.6 m and after the days work when depth or filling becomes about 1.5 m, it is covered by earth layer of about 15 to 30 cm thickness.
 - Filling is done by a grid pattern, (i.e. dividing the entire site into smaller portions).
 - Before dumping the second layer, compaction is done by movement of bull dozers, trucks etc.
 - A minimum clearance distance of 6 m from the surrounding area should be left during filing operation or low lying areas.
 - Insecticides like DDT, creosote etc. should be sprayed to prevent mosquito breeding.
 - Final cover of about 0.6 m of earth is laid and compacted at the top of filled up land in order to finish the complete operation and prevent rodents from burrowing into the refuse.
 - The filled up refuse gets stabilized due to the decomposition of organic matter in due course of time;

subsequently getting converted into stable compounds.

9.8.1 STEPS INVOLVING REFUSE STABILIZATION

The entire period of refuse stabilisation can be divided into five distinct phases

- i) Aerobic bacteria and fungi, which are dominant, deplete the available oxygen to affect oxidation of organic matter. As a result of aerobic respiration, the temperature in the fill increases.
- ii) Anaerobic and facultative bacteria develop to decompose the organic matter; And H_2 and CO_2 gases are thus evolved through acetogenic activity.
- iii) Methanogenic bacteria develop to cause evolution of methane gas.
- iv) Methanogenic activity subsides, representing depletion of the organic matter; And ultimately, the system returns to aerobic conditions within the land fill.

Note: The refuse, in managed landfills, generally gets stabilized, within a period of 2 to 4 Months and settle down by 20 – 40% of its original height. Hence, filled up can be used for developing some green land, parks, or other recreational spots.

9.8.2 ADVANTAGES

- i) This method is most simple and economical. No costly plant or equipment is required in this method
- ii) Separation of different kinds of refuse is also not required in this method.
- iii) No residues or by products left out/evolved in this method, and hence no further disposal is required
- iv) Low lying water-logged areas and quarry pits can be easily reclaimed and put to better use.

9.8.3 DISADVANTAGES

- i) Low lying depressions or dumping sites may not always be available as they

may become scarce or unavailable in future.

- ii) There is a continuous evolution of foul gases near the fill site, especially during the time of dumping the refuse. These gases may often be explosive in nature, and are produced by the decomposing or evaporating organic matter.

9.8.4 OCCURRENCE OF GASES AND LACTATES IN LANDFILLS

The following events occur when solid wastes are placed in a sanitary landfill;

- i) biological decay of organic materials (aerobically/anaerobically) with the evolution of gases and liquids,
- ii) chemical oxidation of waste materials,
- iii) escape of gases from the fill,
- iv) movement of liquids caused by differential heads,
- v) dissolving and leaching of organic and inorganic materials by water and leachate moving through the fill;
- vi) movement of dissolved material by concentration gradients and osmosis,
- vii) uneven settlement caused by consolidation of material into voids.

9.8.5 GASES IN LANDFILLS

- Gases found in landfills include air, ammonia, carbon dioxide, carbon monoxide, hydrogen, hydrogen sulfate, methane, nitrogen. carbon dioxide are the principal gases produced from the anaerobic decomposition of the organic solid-waste components.
- The movement of gas in landfills can be controlled by constructing vents and by gas recovery.
- The movement of landfill gases can be controlled by the landfill sealants.
- Compacted clay is most commonly used as landfill sealants.

9.8.6 LEACHATE IN LANDFILLS

- Leachate may be defined as liquid that has percolated through solid waste and has extracted dissolved or suspended materials from it.
- In most landfills, the liquid portion of the leachate is composed of the liquid produced from the decomposition of the wastes and liquid that has entered the landfill from external sources, such as surface drainage, rainfall, groundwater, and water from underground springs.
- Under normal conditions, leachate is found at the bottom of landfills. From there, it moves through the underlying strata (although some lateral movement may also occur) depending on the characteristics of the surrounding material.
- The use of clay liners or synthesis linear like geotextiles has been the most method favorable method for reducing and eliminating the percolation of leachate.
- An important method to control the production of leachate is to eliminate the nitrification of surface water from the landfill which is the major contributor to the total volume of the leachate. For this we use an impervious clay layer over the top of the fill at a decent slope, provided with adequate drainage and surface nitrification.

10.1 INTRODUCTION

Air pollution is defined as the excessive concentration of foreign matter in the air which adversely affects the well-being of individual or causes damage to the property. It also affects plants, animals and buildings.

10.2 SOURCES OF AIR POLLUTION

1. Natural sources of air pollution
2. Man-made sources of air pollution

10.2.1 NATURAL SOURCES OF AIR POLLUTION

1. Products from atmospheric reactions (chemical reactions like oxidation, combination, polymerization, photochemical reactions etc.):
2. Aerosols-Particulates: Aerosols are finely divided solid or liquid particles of microscopic size held suspended and dispersed in atmosphere. They cause visibility reduction, soiling of surfaces, corrosion etc.
The various types of aerosols are (a) dust, (b) smoke, (c) mists, (d) fog, (e) haze, (f) fumes.
3. Micro-organisms: Infect plants and animals.
4. Pollens: Pollens are the small grains from the anthers of flowers which may cause allergic reaction.
5. Radioactive minerals:
6. Volcanic ash and gases:
7. Gases and odour from swamps and marshy lands.

10.2.2 MAN-MADE SOURCES OF AIR POLLUTION

- i) Combustion of fuels: $(CO_2), (SO_2), (NO_2)$, etc. accumulate in the atmosphere.

- ii) Industries: Emit undesirable gases $(SO_2, CO_2, NO_2, NH_3, CO)$.
- iii) Thermal Power Plants: Mainly they emit Sulphur dioxide.
- iv) Automobiles: Exhaust contains carbon monoxide (CO), methane, un-burnt carbon. CO is the main source of air pollution in congested cities.
- v) Agricultural activities: Crop spraying and field burning.
- vi) Nuclear Power Plants: Emit various radioactive substances.

10.3 CLASSIFICATION OF AIR POLLUTANTS

According to the manner in which they are formed they are classified as:

- i) Primary air pollutants, and
- ii) Secondary air pollutants.

Primary air pollutants are those which are emitted directly from the identifiable sources.

E.g.:

- a. Particulate matter such as dust and aerosols,
- b. Pollens
- c. Sulphur compounds (SO_2, SO_3, H_2S)
- d. Nitrogen compounds (NO, NO_2, NH_3)
- e. Carbon monoxide (CO) and carbon dioxide (CO_2)
- f. Photochemical oxidants
- g. lead
- h. Hydrocarbons
- i. Radioactive materials
- j. Halogen compounds (Hydrogen fluoride, hydrochloric acid)

Secondary air pollutants are those which are formed in the atmosphere as a result of interaction between two or more primary air pollutants or by reactions with the normal atmospheric constituents with or

without photo activation. These are more harmful.

E.g.

1. Sulphuric acid
2. Ozone
3. Formaldehyde
4. Peroxy-acetyl-nitrate(PAN)
5. Photochemical smog

Sulphuric acid (H_2SO_4) is formed by simple chemical reaction between sulphur dioxide (SO_2) and water (H_2O) vapour. It causes acid rains.

Ozone, formaldehyde, peroxy-acetyl-nitrate (PAN), etc., are formed by photochemical reactions caused by sunlight between two primary pollutants.

10.4 CHARACTERISTICS OF AIR POLLUTANTS

Sulphur dioxide (SO_2): It is one of the most important air pollutant and exists where ever fossil fuels are burnt. Thermal plants produce the largest quantity of SO_2 .

Carbon Monoxide (CO): The automobile exhausts are the main contributors CO. The (CO) causes asphyxia i.e., loss of consciousness as a result of too little oxygen and too much carbon dioxide in the human blood.

Hydrocarbons and Photochemical oxidations: Hydrocarbons are mainly released into the atmosphere by automobile exhausts.

Lead: It is mainly injected into the atmosphere from the automobile exhausts, particularly by the automobiles running on petrol. They cause irritation of mucous membranes of nose, throat and lungs.

Oxides of Nitrogen: These are the second most abundant pollutants of air in many cities ranking next to SO_2 . The oxides of nitrogen are produced from air oxidation, electrical discharge and solar radiations, incineration plants, welding operation etc.

10.5 EFFECTS OF AIR POLLUTION

10.5.1 EFFECT ON HUMAN HEALTH

- i) Bronchitis, asthma, etc., are aggravated by high concentrations of sulphur dioxide (SO_2), nitrogen dioxide (NO_2), Photo chemical smog
- ii) Pollens cause asthma
- iii) Lead poisoning is caused by the entry of lead into the lungs.
- iv) Hydrogen fluoride causes bone fluorosis and mottling of teeth.
- v) Carbon monoxide (CO) may cause death by asphyxiation.
- vi) Radioactive radiations may cause
 - a) cancer,
 - b) shortening of life span and
 - c) genetic defects.
- vii) Oxides of Nitrogen: Causes eye and nasal irritation, respiratory discomfort. Respiratory illness among children is very common due to this.
 - a) **Effect on trees and plants:** The air pollutants affecting trees and plants are sulphur dioxide, hydrogen fluoride, etc.
 - b) **Effect on animals:** Fluorine, arsenic and lead may cause contamination of vegetation and affecting the animals when they eat it.
 - c) **Effect on physical features** of the atmosphere:
 - i) Effect on visibility
 - ii) Effect on atmospheric constituents
 - iii) Green-house effect
 - iv) Ozone layer depletion
 - v) Acid rain
 - vi) Global warming
 - d) **Effects on visibility:** Fog and photochemical smog reduce the visibility considerably.
 - e) **Effects on atmospheric constituent:** Carbon dioxide CO_2 is considered as a factor responsible for rise in ambient temperature.

Green-house effect:

Cause: Gases like CO_2 , nitrogen oxide, ozone and chemical like chlorofluorocarbon (CFC) are responsible for green house effect. Carbon dioxide CO_2 is the chief gas responsible for the Green-house effect.

Effect: It causes appreciable rise in temperature of earth's surface.

Remedy: Green house effect can be tackled by reducing the rate at which the fossil fuels like coal are burnt.

Ozone layer depletion:

Cause: This ozone layer acts as an umbrella against the harmful ultraviolet radiation reaching the earth. When chemical pollutants such as chlorofluorocarbon (CFC) emitted from refrigeration and other industrial operations, nitrous oxide pollute the atmosphere and some of the ozone is broken down and it results in decrease of ozone concentration in the atmosphere. In consequence, more ultraviolet radiation reaches the earth.

Effects: 1. Damage of immune system, 2. Disturbance in ecosystem, 3. Effect on crop yield, 4. Increase of skin cancer and eye ailments, 5. Shorter life of paints and plastic.

Remedy: For protecting the ozone layer, the emission of chlorofluorocarbon (CFC) should be restricted.

Acid rain: The rain water is slightly acidic. The acidity level increases with SO_2 , NO_2 etc., The acidity in rain water is caused due to the formation of secondary pollutants such as sulphuric acid (H_2SO_4), nitric acid (HNO_3) and hydrochloric acid (HCl) due to the reaction of water vapours with these gases.

It has been specified that when the pH of the rain water is less than or equal to 5 the rain termed as acid rain. 2/3 of acid rains is due to SO_2 , which is produced mainly by the burning of coal and oil in industries. The SO_2 pollutant leads to H_2SO_4 acidity.

Another primary pollutant responsible for 1/3 of acid rains is NO_x which is produced mainly by the automobile emissions. The NO_x pollutant leads to HNO_3 acidity. Acidic rain damage forests, crops, buildings, monuments (eg: Taj Mahal monument).

Global warming: Global warming is considered to be the outcome of the air pollution caused by the man-made sources. The global warming may lead to burning of crops and may also cause forest fires.

10.6 METHODS OF CONTROLLING AIR POLLUTION

1. Control of air pollution by zoning.
2. Dilution of source discharge by use of tall stacks (Chimneys)
3. Control by using source correction methods (By changing raw materials, process methods, equipment etc).
4. Reduction of pollutant discharge at source by use of controlling equipment.

10.6.1 CONTROL OF AIR POLLUTION BY ZONING

By proper zoning, the city should be planned in such a way that residential areas and heavy industries are not located too close to each other. Providing a green belt between the industries and the township, will reduce the impact of air pollution.

10.6.2 EQUIPMENT FOR CONTROL OF PARTICULATE POLLUTANTS FROM THE GAS STREAM

1. Gravity settling chambers
2. Cyclonic separators or cyclones
3. Fabric filters
4. Electrostatic precipitations
5. Scrubbers or wet collectors

Electro precipitations: They utilize electrical energy for removal of the particulate matter from gaseous stream.

Particles as small as 0.1μ size can be removed by these devices. Generally used to separate fly ash particles from flue gases in thermal power plants.

Scrubbers or wet collectors: Scrubbers are the devices which utilize a liquid to assist in the removal of particulates from the carrier gas stream. Generally water is used as the scrubbing liquid. Particles less than 0.2μ can also be removed.

10.7 CONTROL OF GASEOUS POLLUTANTS

The emission of gaseous pollutants can be controlled by the following methods:

- i) Absorption, ii) Adsorption, and
 - iii) Combustion or incineration
- i) Absorption:** It is a process that involves the transfer of the pollutants from the gas phase to the liquid phase across the interface in response to a concentration gradient set up across the interface. The pollutants commonly controlled by absorption are sulphur dioxide, hydrogen sulphide, nitrogen oxides and light hydrocarbons. The equipment which works on this principle are spray towers, packed towers, venturi-scrubbers.
- ii) Adsorption:** It is the process of capturing and retention of gas molecules from the gas phase by the surface of the solid adsorber or adsorbent. The commonly used adsorbers or adsorbents are activated carbon, activated alumina, molecular sieves such as dehydrated zeolites, silica gel, etc.
- iii) Combustion or incineration:** It may be used when the pollutants in the gas stream are oxidized to an inert gas. Pollutants like hydrocarbons and carbon monoxides can be easily burnt, oxidized and removed.

10.8 SMOKE AND ITS CONTROL

Smoke is a product of incomplete combustion of fuel and hence contains

mainly carbon particles. For estimating the density of smoke, the most commonly used method is the **Ringlemann chart** method.

10.9 METEOROLOGICAL FACTORS INFLUENCING AIR POLLUTION

Wind direction and speed: The higher the wind speed, the more rapidly the pollutants would be carried away from the source and concentration of the pollutants will get decreased.

Atmospheric stability and temperature inversions: The degree of stability of the atmosphere depends upon the rate of change of temperature of the air with altitude.

a) Lapse Rate: The rate of change of temperature of air with altitude is known as "Lapse rate" (Environment Lapse Rate, ELR). In the lower atmosphere (known as troposphere) up to a distance of about 11 km above the earth's surface, the temperature decreases linearly with increases in altitude. In the upper region of the atmosphere which is known as stratosphere which extends from about 11 km to 32 km, constant temperature prevails.

b) Adiabatic Lapse Rate (ALR): The internal decrease of temperature with height which occurs in the rising parcel of air mass can be theoretically calculated by assuming the cooling process to be adiabatic (i.e. occurring without the addition or loss of heat). This rate of decrease of temp. with height is referred to as Adiabatic Lapse Rate (ALR).

c) Super-Adiabatic Lapse Rate (SALR): When the prevailing environmental Lapse Rate (ELR) is greater than the ALR, the ELR is known as Super - Adiabatic Lapse Rate.

In such a case, the rising parcel of air will always remain warmer and lighter than the surrounding environment and

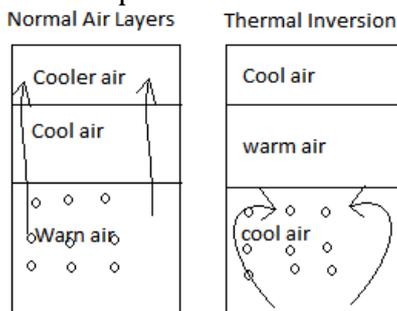
the parcel of air will continue to accelerate and go up. In such a case, the atmospheric condition is said to be 'unstable' and the dispersion of the pollutants will be rapid, effective and less intensity of air pollution.

d) Sub-Adiabatic Lapse Rate: When the prevailing environmental lapse rate (ELR) is less than the ALR, then the ELR is known as sub-adiabatic lapse rate.

In such a case, the rising parcel of air will be cooling more quickly than its surroundings and hence it will not be able to rise up to greater altitudes. Such an atmospheric condition is said to be 'stable' which is however, not favorable for effective dispersion of the pollutants. It results in more pollution.

e) Neutral atmosphere: When the prevailing ELR is equal to the ALR, the atmospheric condition is said to be neutral.

f) Negative Lapse Rate: When the temp of the ambient air increases with increase in altitude, then the lapse rate is termed as negative or inverted lapse rate. The condition under which negative lapse rate occurs is referred to as "inversion". During inversion the atmosphere is said to be stable. It results in more pollution



Inversion: It is an atmospheric condition in which a layer of warm air traps cool air near the surface of the earth thus preventing the normal rising of surface. Therefore pollutants will not disperse in the air. Inverse is a frequent occurrence in the winter and autumn seasons. During inversion the atmosphere is said to be stable. It results in more pollution.

Precipitation: It cleans the atmosphere. Rainfall removes the particulate matter from the atmosphere and also reduces the concentration of gaseous pollutants which are soluble in water.

Humidity: It influences the corrosive action of the air pollutants and also fog formation.

Plume: It is defined as the path taken by gaseous effluents emitted continuously from a specific outlet such as chimney or stack or vent.

10.10 SUSPENDED PARTICULATES AND GASEOUS CONTAMINANTS

Units: mass per unit volume...micrograms per m³ (μg/m³) or in ppm.

For gases, the ppm can be converted to μg/m³ by the following formula

$$\mu\text{g}/\text{m}^3 = \frac{\text{ppm} \times \text{g mol mass} \times 10^3}{\text{L/mol}}$$

Avogadro's law: One mole of any one gas occupies the same volume as one mole of any other gas at the same temperature and pressure.

At 273°K (0°C) and 1 atm pressure (760 mm Hg), the volume of gas is 22.4 L/mol.

To convert to liters per mole at other conditions the formula is $\frac{V_1 P_1}{T_1} = \frac{V_2 P_2}{T_2}$

Where V_1, P_1 and T_1 relate to the above conditions of 22.4 L/mol at 273°K and 760 mm Hg.

V_2, P_2 and T_2 relate to the actual conditions being considered.

GATE QUESTIONS

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1

WATER DEMAND

Q.1 The present population of a community is 28000 with an average water consumption of 4200 m³/d. The existing water treatment plants has a design capacity of 6000 m³/d. It is expected that the population will increase to 44000 during the next 20 years .the number of years from now when the plant will reach its design capacity, assuming an arithmetic rate of population growth, will be
 a) 5.5 years b) 8.6 years
 c) 15.0 years d) 16.5 years

[GATE-2004]

Q.2 A conventional flow duration curve is a plot between
 a) Flow and percentage time flow is exceeded
 b) Duration of flooding and & ground level elevation
 c) Duration of water supply in a city and proportion of area receiving supply exceeding this duration
 d) Flow rate and duration of time taken to empty a reservoir at that flow rate

[GATE-2014]

ANSWER KEY:

| | |
|----------|----------|
| 1 | 2 |
| (c) | (a) |

EXPLANATIONS

Q.1 (c)
 $P_0 = 28,000$
 Average increase per decade, $\ddot{x} = \frac{44,000 - 28,000}{2} = 8,000$
 4200m³r required for 28,000 persons
 6000m³r sufficient for persons
 $= \frac{28000 \times 6000}{4200} = 40,000$
 $P_n = P_0 + n\ddot{x}$
 $40,000 = 28,000 + n.8,000$
 $n = 1.5$ decades
 = 15 years

Q.2 (a)

2

QUALITY CONTROL OF WATER SUPPLIES

- Q.1** Use of coagulants such as alum
- a) results in reduction of pH of the treated water.
 - b) results in increase of pH of the treated water.
 - c) results in no change in pH of the treated water.
 - d) may cause and increase or decrease of pH of the treated water

[GATE-2000]

- Q.2** Aeration of water is done to remove
- a) Suspended Impurities
 - b) Color
 - c) Dissolved Salts
 - d) Dissolve Gases

[GATE-2001]

- Q.3** The Ca^{2+} concentration and Mg^{2+} concentration of a water sample are 160 mg/lit and 40 mg/lit as their ions respectively. The total hardness of this water sample in terms of CaCO_2 in mg/lit is a approximately equation equal to
- a) 120
 - b) 200
 - c) 267
 - d) 567

[GATE-2001]

- Q.4** The following chemical is used for coagulation
- a) Ammonium Chloride
 - b) Aluminium Chloride
 - c) Aluminium Sulphate
 - d) Copper Sulphate

[GATE-2001]

- Q.5** The theoretical oxygen demand of a 0.001 mol/L glucose solution is
- a) 180 mg/L
 - b) 192mg/L
 - c) 90 mg/L
 - d) 96 mg/L

[GATE-2002]

- Q.6** In natural water, hardness is mainly caused by

- a) Ca^{++} and Mn^{++}
- b) Ca^{++} and Fe^{++}
- c) Na^+ and K^+
- d) Ca^{++} and Mg^{++}

[GATE-2002]

Common data for Que. 7 & 8:

A water treatment plant treating 10mld of water requires 20 mg/l of filter Alum, $\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O}$. The water has 6 mg/l of alkalinity as CaCO_3 (Al = 26.97, S = 32, O = 16, H = 1, Ca = 40, and C = 12)

- Q.7** Total alkalinity requirement (10^6 mg per day as CaCO_3) matching filter Alum, shall be
- a) 180
 - b) 120
 - c) 90
 - d) 60

[GATE-2003]

- Q.8** Quantity of Quick lime required (10^6 mg per year as year as CaO) shall b
- a) 2132
 - b) 3000
 - c) 4132
 - d) 6132

[GATE-2003]

- Q.9** The results of analysis of a raw water sample are given below

| | |
|----------------|---------------|
| Turbidity | 5 mg/1 |
| pH | 7.4 |
| Fluorides | 2.5 mg/1 |
| Total Hardness | 300 mg/1 |
| Iron | 3.0 mg/1 |
| MPN | 50 per 100 ml |

From the data given above, it can be inferred that water needs removal of

- a) Turbidity followed by disinfection
- b) Fluorides and Hardness
- c) Iron, followed by disinfection
- d) Both (b) and (c)

[GATE-2003]

- Q.10** Results of a water sample analysis are as follows:

| Cation | Concentration (mg/1) | Equivalent Weight |
|------------------|----------------------|-------------------|
| Na^+ | 40 | 23 |
| Mg^+ | 10 | 12.2 |
| Ca^{+2} | 55 | 20 |
| $-\text{K}^+$ | 2 | 39 |

(milliequivalent weight of $\text{CaCO}_3 = 50\text{mg/meq}$). Hardness of the water sample in mg/l as CaCO_3 is

- a) 44.8 b) 89.5
c) 179 d) 358

[GATE-2003]

Q.11 Most of the turbidity meters work on the scattering principle. The turbidity value obtained is expressed in

- a) CFU b) FTU
c) JTU d) NTU

[GATE-2004]

Q.12 Hardness of water is directly measured by titration with ethylene-di-amine-tetracetic acid (EDTA) using

- a) eriochrome black T indicator
b) ferroin indicator
c) methyl orange indicator
d) phenolphthalein indicator

[GATE-2004]

Q.13 The organism, which exhibits very nearly the characteristics of an ideal pathogenic indicator is

- a) Entamoeba histolytica
b) Escherichia coli
c) Salmonella typhi
d) Vibrio comma

[GATE-2004]

Q.14 A standard multiple-tube fermentation test was conducted on a sample of water from a surface stream. The results of the analysis of the confirmed test are given below

| Sample size (ml) | No. of positive results out of 5 tubes | No. of negative results out of 5 tubes |
|------------------|--|--|
| 1.0 | 4 | 1 |
| 0.1 | 3 | 2 |
| 0.01 | 1 | 4 |

MPN Index and 95% confidence limits for combination of positive results when five tube used per dilution (10ml, 1.0ml, 0.1ml)

| Combina tionOf Positives | MPN Index per 100 ml | 95% confidence limit | |
|--------------------------------|-------------------------------|-------------------------|-------|
| | | Lower | Upper |
| 4-2-1 | 26 | 12 | 65 |
| 4-3-1 | 33 | 15 | 77 |

Using the above MPN Index table, the most probable number (MPN) of the sample is

- a) 26 b) 33
c) 260 d) 330

[GATE-2004]

Q.15 Match the following:

Group I

- P. Release valve
Q. Check valve
R. Gate valve
S. Pilot valve

Group II (Type of water impurity)

- Reduce high inlet pressure to lower outlet pressure
- Limit the flow of water to single direction
- Remove air from the pipeline
- Stopping the flow of water in the pipeline

Codes:

| | P | Q | R | S |
|----|---|---|---|---|
| a) | 3 | 2 | 4 | 1 |
| b) | 4 | 2 | 1 | 3 |
| c) | 3 | 4 | 2 | 1 |
| d) | 1 | 2 | 4 | 3 |

[GATE-2005]

Q.16 1 TCU is equivalent to the colour produced by

- a) 1 mg/L of chlorplatin ion
b) 1 mg/L of platinum ion
c) 1 mg/L of platinum in form of chlorplatin ion
d) 1 mg/L of organo-chlorplatin ion

[GATE-2005]

Q.17 Total Kjeldahl nitrogen is a measure of

- a) total organic nitrogen
b) total organic and ammonia nitrogen

- c) total ammonia nitrogen
d) total inorganic and ammonia nitrogen

[GATE-2005]

- Q.18** If tomato juice is Having a pH of 4.1, the hydrogen ion concentration will be
a) 10.94×10^{-5} mol/L
b) 9.94×10^{-5} mol/L
c) 8.94×10^{-5} mol/L
d) 7.94×10^{-5} mol/L

[GATE-2005]

- Q.19** A synthetic sample of water is prepared by adding 100 mg Kaolinite (a clay mineral), 200 mg glucose, 168 mg NaCl, 120 mg $MgSO_4$, and 111 mg $CaCl_2$ to 1 liter of pure water. The concentrations of total solids (TS) and fixed dissolved solids (FDS) respectively in the solution in mg/L are equal to
a) 699 and 599 b) 599 and 399
c) 699 and 199 d) 699 and 399

[GATE - 2006]

Statement for linked Answer Q.20 & Q.21

A water sample contains the following dissolved ion.

$$[Na^+] = 56 \text{ mg/L}; [Ca^{2+}] = 40 \text{ mg/L};$$

$$[Mg^{2+}] = 30 \text{ mg/L}; [Al^{3+}] = 3 \text{ mg/L};$$

$$[HCO_3^-] = 190 \text{ mg/L}; [Cl^-] = 165 \text{ mg/L};$$

Water pH is 7. Atomic weights: Ca:40; Mg:24; Al:27; H:1; C:12; O:16; Na:23; Cl:35.5

- Q.20** The total hardness of the sample in mg/l as $CaCO_3$ is
a) 484 b) 450
c) 242 d) 225

[GATE-2006]

- Q.21** The non-carbonate hardness of the sample in
a) 225 b) 156
c) 69 d) 0

[GATE-2006]

- Q.22** The presence of hardness in excess of permissible limit causes

- a) Cardio Vascular problems
b) Skin discolouration
c) Calcium deficiency
d) Increased laundry expenses

[GATE-2007]

- Q.23** The alkalinity and the hardness of a water sample are 250 mg/L and 350 mg/L as $CaCO_3$, respectively. The water has
a) 350 mg/L carbonate hardness and zero non-carbonate hardness.
b) 250 mg/L carbonate hardness and zero non-carbonate hardness.
c) 250 mg/L carbonate hardness and 350 non-carbonate hardness.
d) 250 mg/L carbonate hardness and 100 non-carbonate hardness.

[GATE-2007]

- Q.24** A wastewater sample contains $10^{-5.6}$ mmol/l of OH ion at 25°C. The pH of this sample is
a) 8.6 b) 8.4
c) 5.6 d) 5.4

[GATE-2008]

- Q.25** Group I lists estimation methods of some of the water and wastewater quality parameters. Group II lists the indicators used in the estimation method. Match the estimation method (Group I) with the corresponding indicator (Group II)

Group I

- P. Azide modified Winkler method for dissolved oxygen
Q. Dichromate method for chemical oxygen demand
R. EDTA titrimetric method for Hardness
S. Mohr or Argentometric method for Chlorides

Group II

1. Eriochrome Black T
2. Ferrion
3. Potassium chromate
4. Starch

Codes:

- a) P-3, Q-2, R-1, S-4
- b) P-4, Q-2, R-1, S-3
- c) P-4, Q-1, R-2, S-3
- d) P-4, Q-2, R-3, S-1

[GATE-2008]

Common data for Question 26 & 27:

Following chemical species were reported for water sample from a well:

| Species | Concentration (milli equivalent/L) |
|--|------------------------------------|
| Chloride (CL) | 15 |
| Sulphate (SO ₄ ²⁻) | 15 |
| Carbonate (CO ₃ ²⁻) | 05 |
| Bicarbonate (HCO ₃ ⁻) | 30 |
| Calcium (Ca ²⁺) | 12 |
| Magnesium (Mg ²⁺) | 18 |
| pH | 8.5 |

- Q.26** Total hardness in mg/L as CaCO₃ is
- a) 1500
 - b) 2000
 - c) 3000
 - d) 5000

[GATE-2009]

- Q.27** Alkalinity present in the water in mg/L as CaCO₃ is
- a) 250
 - b) 1500
 - c) 1750
 - d) 500

[GATE-2009]

Common data for Question 28 & 29:

| Ion | Ca ²⁺ | Mg ²⁺ | Na ⁺ | HCO ₃ | SO ₄ ²⁻ | Cl ⁻ |
|--------------------------|------------------|------------------|-----------------|-----------------------|-------------------------------|-----------------|
| Ion Concentration (mg/L) | 100 | 6 | 15 | 250 | 45 | 39 |
| Atomic Weight | Ca = 40 | Mg = 24 | Na = 23 | H = 1, C = 12, O = 16 | S = 32, O = 16 | Cl = 35.5 |

- Q.28** Total hardness (mg/L as CaCO₃) present in the above water sample is
- a) 205
 - b) 250
 - c) 275
 - d) 308

[GATE-2010]

- Q.29** Carbonate hardness (mg/L as CaCO₃) present in the above water sample is
- a) 205
 - b) 250
 - c) 275
 - d) 289

[GATE-2010]

- Q.30** An aerobically treated effluent has MPN of total coliform as 10⁶/100 mL. After chlorination, the MPN value declines to 10²/100 mL. The percent removal (%R) and log removal (log R) of total coliform MPN is

- a) %R = 99.90; log R = 4
- b) %R = 99.90; log R = 2
- c) %R = 99.99; log R = 4
- d) %R = 99.90; log R = 2

[GATE-2011]

- Q.31** Chlorine gas (8 mg/L as Cl₂) was added to a drinking water sample. If the free chlorine residual and pH was measured to be 2 mg/L (as Cl₂) and 7.5, respectively, what is the concentration of residual OCl⁻ ions in water? Assume that the chlorine gas added to the water is completely converted to HOCl and OCl⁻. Atomic Weight of Cl: 35.5

- OCl⁻ + H⁺ ⇌ HOCl, K = 10^{7.5}
- a) 1.408 × 10⁻⁵ moles/L
 - b) 2.817 × 10⁻⁵ moles/L
 - c) 5.634 × 10⁻⁵ moles/L
 - d) 1.127 × 10⁻⁵ moles/L

[GATE-2011]

- Q.32** A water sample has a pH of 9.25. The concentration of hydroxyl ion in the water sample is
- a) 10^{-9.25} moles/L
 - b) 10^{-4.75} moles/L
 - c) 0.302 mg/L
 - d) 3.020 mg/L

[GATE-2012]

- Q.33** Some of the nontoxic metals normally found in natural water are
- a) arsenic, lead and mercury
 - b) calcium, sodium and silver
 - c) cadmium, chromium and copper
 - d) iron, manganese and magnesium

[GATE-2014]

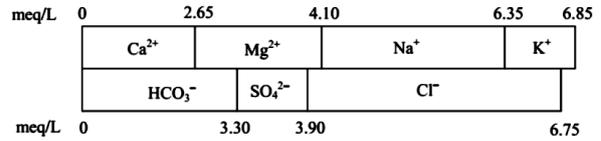
Q.34 A groundwater sample was found to contain 500 mg/L total dissolved solids (TDS). TDS (in %) present in the sample is ____

[GATE-2015]

Q.35 The hardness of a ground water sample was found to be 420 mg/L as CaCO₃. A softener containing ion exchange resins was installed to reduce the total hardness to 75 mg/L as CaCO₃ before supplying to 4 households. Each household gets treated water at a rate of 540 L/day. If the efficiency of the softener is 100%, the bypass flow rate (expressed in L/day) is

[GATE-2016]

Q.36 A sample of water has been analyzed for common ions and results are presented in the form of a bar diagram as shown.



The non-carbonate hardness (expressed in mg/L as CaCO₃) of the sample is

- a) 40
- b) 165
- c) 195
- d) 205

[GATE-2016]

ANSWER KEY:

| | | | | | | | | | | | | | |
|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| (a) | (d) | (d) | (c) | (d) | (d) | (c) | (d) | (d) | (c) | (b) | (a) | (b) | (d) |
| 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 |
| (a) | (c) | (b) | (b) | (d) | (c) | (c) | (d) | (d) | (d) | (b) | (a) | (c) | (c) |
| 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | | | | | | |
| (a) | (c) | (a) | (c) | (d) | * | | (a) | | | | | | |

EXPLANATIONS

- Q.1 (a)** $= 3 \times 0.56 = 1.68 \text{ mg/Lit}$
 Total quick lime required per year =

$$\frac{1.68 \times 10 \times 10^6 \times 365}{10^6}$$
- Q.2 (d)**
- Q.3 (d)**

$$\text{T.H.} = \text{Ca}^{++} \times \frac{50}{20} + \text{Mg}^{++} \times \frac{50}{12}$$

$$\text{T.H.} = 160 \times \frac{50}{20} + 40 \times \frac{50}{12}$$

$$\text{T.H.} = 567$$
- Q.4 (c)**
- Q.5 (b)**

$$\text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \rightarrow 6\text{CO}_2 + 6\text{H}_2\text{O}$$
 180 part of glucose demand 192
 part of $\text{O}_2 = 0.001 \times 180 \times 1000 = 180$
 0.001 moles/lit of glucose means
 180mg/lit

$$\left\{ \frac{\text{mg}}{\text{lit}} = \frac{\text{moles}}{\text{lit}} \times \text{md.wt.} \times 1000 \right\}$$
- Q.6 (d)**
- Q.7 (c)**
 $Q = 10\text{MLD} = 10 \times 10^6 \text{ Lit/day}$
 Alum = 20 mg/Lit
 1 mg of Alum requires 0.45 mg of
 Alkaline as CaCO_3
 $\therefore 20 \text{ mg/Lit of alum requires}$
 $= 20 \times 0.45 = 9 \text{ mg of alkaline as}$
 $\text{CaCO}_3 \text{ per Lt of water}$
 $\therefore \text{Total alkalinity matching filter}$
 $\text{Alum} = 9 \text{ mg/Lit} = 10 \times 10^6 \text{ Lit/day} =$
 90×10^6
 Total alkalinity requirement (10^6
 mg per day) = 90
- Q.8 (d)**
 Natural available alkalinity = 6
 mg/Lit
 $\therefore \text{Alkalinity to be added additionally}$
 $= 9 - 6 = 3 \text{ mg/Lit}$
 $\therefore \text{Alkaline to be added to the water}$
- Q.9 (d)**
- Q.10 (c)**

$$\text{TH} = \text{Ca}^{++} \times \frac{50}{20} + \text{Mg}^{++} \times \frac{50}{12}$$

$$= 55 \times \frac{50}{20} + 10 \times \frac{50}{12}$$

$$= 179 \text{ mg/lit}$$
- Q.11 (b)**
- Q.12 (a)**
- Q.13 (b)**
- Q.14 (d)**
 Positive combination: 4 - 3 - 1
 MPN from the table = 33

$$\text{Correct MPN} = \frac{\text{MPN value from the table}}{\text{Largest volume tested}} \times 100$$

$$= 33 \times 10 = 330$$
- Q.15 (a)**
 All of these are pipe appurtenances
 which are required for the proper
 functioning of the pipeline.
- Q.16 (c)**
- Q.17 (b)**
 The sum total of organic nitrogen
 and ammonia nitrogen is called
 Kjeldahl nitrogen.
- Q.18 (d)**

$$P_H \log_{10} \left(\frac{1}{H^+} \right)$$

$$4.1 = \log_{10} \left(\frac{1}{H^+} \right)$$

$$H^+ = 7.94 \times 10^{-5} \text{ mol/L}$$

Q.19 (d)

Total solids:

$$100 + 200 + 168 + 120 + 111$$

$$= 699 \text{ mg/l}$$

Fixed dissolved solids = inorganic solids

$$= 168 + 120 + 111 = 399 \text{ mg/l}$$

Q.20 (c)

$$TH = 40 \times \frac{50}{20} + 30 \times \frac{50}{12}$$

$$= 225 \text{ mg/lit as CaCO}_3$$

Q.21 (c)

$$\text{Alkalinity} = 190 \times \frac{50}{61}$$

$$= 155.7 \approx 156 \text{ mg/lit as CaCO}_3$$

TH > Alkalinity

$$NCH = 225 - 156 = 69 \text{ mg/lit}$$

Q.22 (d)

Q.23 (d)

Q.24 (d)

$$OH^- = 10^{-5.6} \text{ m.mol/lit}$$

$$1 \text{ mol of } OH^- = 17g = 1700 \text{ mg}$$

1 milli.mol of OH^-

$$= \frac{17000}{10^3} = 17 \text{ mg}$$

$$10^{-5.6} \text{ milli mol} = 17 \times 10^{-5.6}$$

$$= \frac{10^{-5.6}}{10^3} \text{ mol/lit} = 10^{-8.6} \text{ mol/lit}$$

$$[H^+][OH^-] = 10^{-14}$$

$$H^+ = 10^{-5.4} \text{ mol/lit}$$

$$P^H = \log_{10}[1/H^+] = 5.4$$

Q.25 (b)

Q.26 (a)

TH in mg/lit as $CaCO_3$

$$= Ca^{++} \text{ in mg/lit} \times \frac{50}{20} +$$

$$Mg^{++} \text{ in mg/lit} \times \frac{50}{12}$$

$$= (12 \times 20) \times \frac{50}{20} + (18 \times 12) \times \frac{50}{12} =$$

$$1500 \text{ mg/lit as } CaCO_3$$

Q.27 (c)

Alkalinity in mg/lit $CaCO_3$

$$= HCO_3^- \text{ in mg/lit} \times \frac{50}{61} + CO_3 \text{ in}$$

$$\text{mg/lit} \times \frac{50}{30}$$

$$= (30 \times 61) \times \frac{50}{61} + (5 \times 30) \times \frac{50}{30} =$$

$$1750 \text{ mg/lit as } CaCO_3$$

Q.28 (c)

$$TH = 100 \times \frac{50}{20} + 6 \times \frac{50}{12}$$

$$= 275 \text{ mg/lit as } CaCO_3$$

Q.29 (a)

$$\text{Alkalinity} = 250 \times \frac{50}{61}$$

$$= 204.9 \approx 205 \text{ mg/lit as } CaCO_3$$

Q.30 (c)

Percent removal (%R) =

$$\left(\frac{10^6 - 10^2}{10^6} \right) \times 100 = 99.99\% \log(R) =$$

$$\log 10^6 - \log 10^2$$

$$= 6 - 2 = 4$$

Q.31 (a)

Free residual = $HOCl + OCl^- = 2 \text{ mg/lit as } Cl_2$

$$2(\text{mg/lit}) = Cl_2 \left(\frac{\text{moles}}{\text{lit}} \right) \times \text{Mol.wt} \times$$

$$1000$$

$$\frac{2}{2 \times 35.5 \times 100} = Cl_2 \text{ (moles/lit)}$$

\therefore (free residual) $HOCl + OCl^-$

$$= 2 \text{ mg/lit} = 2.816 \times 10^{-5} \text{ (moles/lit)}$$

$$P^H = 7.5$$

$$\therefore P_H = \log_{10} \left(\frac{1}{H^+} \right)$$

$$\Rightarrow H^+ = 10^{-7.5} \text{ moles/lit}$$

$$\frac{HOCL}{OCL^-} = [K][H^+]$$

$$= 10^{7.5} \times 10^{-7.5}$$

$$\therefore HOCL = OCL^-$$

$$\Rightarrow HOCL + OCL^- = 2 \text{ mg/lit}$$

$$= 2.86 \times 10^{-5} \text{ (moles/lit)}$$

$$\therefore 2 OCL^- = 2.816 \times 10^{-5}$$

$$\therefore OCL^- = 1.408 \times 10^{-5} \text{ moles/lit}$$

$$NCH = TH - \text{Alkalinity} = 205 - 165 = 40 \text{ mg/L}$$

Q.32 (c)

$$pH = 9.25$$

$$pOH = 14 - 9.25 = 4.75$$

$$\therefore OH^- = 10^{-4.75} \text{ mol/l}$$

$$1 \text{ mole of OH}^- = 17 \text{ gm} = 1700 \text{ mg}$$

$$6H^- \text{ in mg} = 10^{-4.75} \times 17000$$

$$= 0.302 \text{ mg/l}$$

Q.33 (d)

Q.34 0.05

$$TDS = 500 \text{ mg/lit}$$

$$1 \text{ lit} = 500 \text{ mg} = 500 \times 10^{-3} \text{ gm}$$

$$\% TDS = \frac{500}{1000} \times 10^{-3} \times 100$$

$$1 \text{ lit} = 1000 \text{ gm}$$

Q.35 (385.7)

Since each household gets water =

$$540 \text{ L/day}$$

So, total treated water =

$$540 \times 4 = 2160 \text{ L/day}$$

Let bypass flow rate is QL/day

So,

$$75 = \frac{Q \times 42.0(2160 - Q) \times 0}{2160}$$

$$\Rightarrow 2160 \times 75 = Q \times 420$$

$$\Rightarrow Q = 385.71 \text{ L/day}$$

Q.36 (a)

Total hardness = Mg/L of Ca^{2+} and Mg^{2+}

$$= 4.1 \times 50 = 205 \text{ mg/L as } CaCO_3$$

$$\text{Alkalinity} = 3.3 \times 50 = 165 \text{ mg/L as } CaCO_3$$

3

WATER TREATMENT

Q.1 The following characteristics pertain to the sand filters in water industry.

- I. filtration rate is 1 to 4 m³/(m²day).
- II. typical duration of operation in one run is 24 to 72 hours.
- III. Operation cost is low.

Which of the above characteristics pertain to slow sand filters?

- a) I, II and III
- b) I and II
- c) II and III
- d) I and III

[GATE-2000]

Q.2 The disinfection efficiency of chlorine in water treatment

- a) is not dependent on pH value.
- b) is increased by increased pH value.
- c) remains constant at all pH value.
- d) is reduced by increased pH value.

[GATE-2000]

Q.3 A town has an existing horizontal flow sedimentation tank with an overflow rate of 17 m³/day/m², and it is desirable to remove particles that having settling velocity of ideal sedimentation tank, the percentage of particles removal is approximately equal to

- a) 30%
- b) 50%
- c) 70%
- d) 90%

[GATE-2001]

Q.4 For a water treatment plant having a flow rate of 432 m³/hr, what is the required plan area of a Type T settling tank to remove 90% of the particles having a settling velocity of 0.12 cm/sec is

- a) 120m²
- b) 111m²
- c) 90m²
- d) 100m²

[GATE-2002]

Q.5 In disinfection, which of the following forms of chlorine is most effective in killing the pathogenic bacteria?

- a) Cl₂
- b) OCl₂
- c) NH₂Cl
- d) HOCl

[GATE-2002]

Q.6 Zero hardness of water is achieved by

- a) lime soda process
- b) excess lime treatment
- c) ion exchange treatment
- d) excess alum and lime treatment

[GATE-2003]

Q.7 Match the following:

Group I (Type of water impurity)

- P. Hardness
- Q. Brackish water from sea
- R. Residual MON from filters
- S. Turbidity

Group II (Type of water impurity)

- 1. Reverse Osmosis
- 2. Chlorination
- 3. Zeolite Treatment
- 4. Coagulation and Flocculation
- 5. Coagulation, Flocculation, and Filtration

Codes:

| | P | Q | R | S |
|----|---|---|---|---|
| a) | 1 | 2 | 4 | 5 |
| b) | 3 | 2 | 2 | 4 |
| c) | 2 | 1 | 3 | 5 |
| d) | 3 | 1 | 2 | 5 |

[GATE-2003]

Q.8 An ideal horizontal flow settling basin is 3m deep having surface area 900m². Water flows at the rate of 8000 m³/d, at water temperature 20°C ($\mu = 10^{-3}$ kg/m.s) and ($\rho = 1000$ kg/m³). Assuming Stokes law to be valid, the proportion (percentage) of spherical sand

than 2.5 NTU. The time for reaching terminal head loss (T_H) is defined as the time elapsed from the start of the filter run to the time when head loss across the filter is greater than 3 m.

- Q.15** The effect of increasing the filter depth (while keeping all other conditions same) on T_B and T_H is
- T_B increases and T_H decreases
 - both T_B and T_H increases
 - T_B decreases and T_H increases
 - both T_B and T_H decreases

[GATE-2006]

- Q.16** The effect of increases the filter loading rate (while keeping all other conditions same) on T_B and T_H is
- T_B increases and T_H decreases
 - both T_B and T_H increases
 - T_B decreases and T_H increases
 - both T_B and T_H decreases

[GATE-2006]

Statement for linked answer Q.17 & Q.18:

A plain sedimentation tank with a length of 20 m, width of 10 m, and a depth of 3m is used in a water treatment plant to treat 4 million litres of water per day (4MLD). The average temperature of water is 20°C. Density of water is 998.2 kg/m³. Average specific gravity of particles is 2.65.

- Q.17** What is the surface overflow rate in the sedimentation tank?
- 20 m³/m²/day
 - 40 m³/m²/day
 - 67 m³/m²/day
 - 133 m³/m²/day

[GATE-2007]

- Q.18** What is the minimum diameter of the particle which can be removed with 100% efficiency in the above sedimentation tank?
- 11.8×10^{-3} mm
 - 16.0×10^{-3} mm
 - 50×10^{-3} mm
 - 160×10^{-3} mm

[GATE-2007]

- Q.19** A water treatment plant is required to process 28800 m³/d of raw is

water (density = 1000 kg/m³, kinematic viscosity = 10⁻⁶ m²/s). The rapid mixing tank imparts a velocity gradient of 900 s⁻¹ to blend 35 mg/l of alum with the flow for a detention time of 2 minutes. The power input (w) required for rapid mixing is

- 32.4
- 36
- 324
- 32400

[GATE-2008]

- Q.20** Consider the following unit processes commonly use in water treatment; rapid mixing (RM), flocculation (F), primary sedimentation (PS), secondary sedimentation (SS), chlorination (C) and rapid sand filtration (RSF). The order of these unit processes (first to last) in conventional water treatment plants is

- PS→RSF→F→RM→SS→C
- PS→F→RM→RSF→RM→C
- PS→F→SS→RSF→RM→C
- PS→RM→F→SS→RSF→C

[GATE-2011]

- Q.21** A town is required to treat 4.2 m³/min of raw water for daily domestic supply. Flocculating particles are to be produced by chemical coagulation. A column analysis indicated that an overflow rate of 0.2 mm/s will produce satisfactory particle removal in a setting surface area (in m²) for setting is

- 210
- 350
- 1728
- 21000

[GATE-2012]

- Q.22** A water treatment plant is designed to treat 1 m³/s of raw water. It has 14 sand filters. Surface area of each filter is 50 m². What is the loading rate (in m³/day.m²) with two filters out of service for routine backwashing?

[GATE-2013]

Q.23 Some of the water quality parameters are measured by titrating a water sample with a titrant. Group – I gives a list of parameters and Group – II gives the list of titrants.

| | |
|---------------------|---|
| Group – I | Group – II |
| P. Alkalinity | 1. N/35.5 AgNO ₃ |
| Q. Hardness | 2. N/40 Na ₂ S ₂ O ₃ |
| R. Chloride | 3. N/50 H ₂ SO ₄ |
| S. Dissolved oxygen | 4. N/50 EDTA |

The correct match of water quality parameters in Group– I with titrants in Group – II is:

- a) P-1,Q-2,R-3,S-4 b) P-3,Q-4,R-1,S-2
c) P-2,Q-1,R-4,S-3 d) P-4,Q-3,R-2,S-1

[GATE-2013]

Q.24 The amount of CO₂ generated (in kg) while completely oxidizing one kg of CH₄ to the end products is _____.

[GATE-2014]

Q.25 16 MLD of water is flowing through a 2.5 km long pipe of diameter 45 cm. The chlorine at the rate of 32 kg/d is applied at the entry of this pipe so that disinfected water is obtained at the exit. There is a proposal to increase the flow through this pipe to 22 MLD from 16 MLD. Assume the dilution coefficient, $n = 1$. The minimum amount of chlorine (in kg per day) to be applied to achieve the same degree of disinfection for the enhanced flow is

- a) 60.50 b) 44.00
c) 38.00 d) 23.27

[GATE-2014]

Q.26 A surface water treatment plant operates round the clock with a flow rate of 35 m³/min. The water temperature is 15°C and jar testing indicated an alum dosage of 25 mg/l with flocculation at a Gt value of 4×10^4 producing optimal results. The alum quantity required for 30 days (in kg) of operation of the plant is _____.

[GATE-2014]

Q.27 Consider a primary sedimentation tank (PST) in a water treatment plant with surface Overflow Rate (SOR) of 40 m³/m²/d. The diameter of the spherical particle which will have 90 percent theoretical removal efficiency in this tank is _____ μm. Assume that settling velocity of the particles in water is described by Stokes's Law.

Given Density of water = 1000 kg/m³; Density of particle = 2650 kg/m³;
 $g = 9.81 \text{ m/s}^2$; Kinematic viscosity of water (ν) = $1.10 \times 10^{-6} \text{ m}^2/\text{s}$

[GATE-2015]

Q.28 A water supply board is responsible for treating 1500 m³/day of water. A settling column analysis indicates that an overflow rate of 20 m/day will produce satisfactory removal for a depth of 3.1 m. It is decided to have two circular settling tanks in parallel. The required diameter (expressed in m) of the settling tanks is _____.

[GATE-2016]

ANSWER KEY:

| | | | | | | | | | | | | | | |
|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| (d) | (d) | (b) | (c) | (d) | (c) | (d) | (c) | (c) | (a) | (b) | (d) | (c) | (c) | (a) |
| 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | | |
| (d) | (a) | (b) | (d) | (d) | (b) | * | (b) | 2.7 | (a) | * | * | * | | |

EXPLANATIONS

Q.1 (d)

Slow sand filters run for a period of 1 to 3 months.

Q.2 (d)

Q.3 (b)

$$\eta = \frac{V_s}{V_0} \times 100$$

$$= \frac{0.1}{\left(\frac{17 \times 1000}{24 \times 3600}\right)} \times 100 = 50.8\%$$

Q.4 (c)

$$\eta = \frac{V_s}{V_0} \times 100$$

$$0.90 = \frac{0.12 \times 10^{-2}}{V_0}$$

$$\Rightarrow V_0 = 1.34 \times 10^{-3} \text{ m/sec}$$

$$A = \frac{Q}{V_0} = \frac{432}{60 \times 60 \times 1.34 \times 10^{-3}}$$

$$= 90 \text{ m}^2$$

Q.5 (d)

Q.6 (c)

Q.7 (d)

Q.8 (c)

$Q = 8,000 \text{ m}^3/\text{day}$
 Surface area (B.L) = 900 m^2

$$V_0 = \frac{Q}{\text{B.L}} = \frac{8000}{900}$$

$$= 8.89 \text{ m/day} = 1.028 \times 10^{-4} \text{ m/sec}$$

As $d < 0.1 \text{ mm}$

$$VS = \frac{g}{18} (s - 1) \times \frac{d^2}{v}$$

$$D = 0.01 \text{ mm} = 1.0 \times 10^{-5} \text{ m}$$

$$V = \frac{\mu}{\rho} = \frac{10^{-3}}{1000} = 10^{-6} \text{ m}^2/\text{sec}$$

$$\therefore V_s = \frac{9.81}{18} [2.65 - 1] \frac{(1.0 \times 10^{-5})^2}{10^{-6}}$$

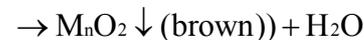
$$= 9 \times 10^{-5} \text{ m/sec}$$

$$\eta = \frac{V_s}{V_0} \times 100 = \frac{9 \times 10^{-5}}{1.028 \times 10^{-4}}$$

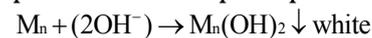
$$= 8.75\%$$

Q.9 (c)

If oxygen present in the water sample M_n (manganese) ion react with OH^- ion O_2 and produce brown precipitate.



If no. oxygen present in the water sample Mn react with OH^- and produce white precipitate.



From this sample X has developed brown precipitate indicates, it contains D.O.

sample Y has developed white precipitate indicates DO is absent.

Q.10 (a)

Q.11 (b)

$$\frac{\text{HOCL}}{(\text{HOCL} + \text{OCL})} \frac{1}{1 + \frac{K_i}{H^+}}$$

$$0.9 = \frac{1}{1 + \frac{2.7 \times 10^{-8}}{H^+}}$$

$$H^+ = 2.43 \times 10^{-7}$$

$$p^H = \log_{10} \left[\frac{1}{H^+} \right]$$

$$\Rightarrow p^H = 6.614$$

Q.12 (d)

Overflow rate = $35 \text{ m}^3/\text{m}^2/\text{day}$

$$Q = 5005 \text{ m}^3/\text{day}$$

$$\therefore \text{Area} = \frac{Q}{\text{O.F.R.}} = \frac{5005}{35}$$

$$\frac{\pi D^2}{4} = 143$$

$$\therefore D = 13.5 \text{ m}$$

Q.13 (c)

Surface area required =

$$\frac{Q}{\text{Design loading rate}}$$

$$A_{\text{req}} = \frac{0.5(\text{m}^3/\text{sec})}{\frac{200}{24 \times 60 \times 60} (\text{m}^3/\text{m}^2/\text{sec})}$$

$$A_{\text{req}} = 216 \text{ m}^2$$

Q.14 (c)

No. of filter required = $\frac{216}{50}$

= 4.32

In all options, greater than 4.32 is 6.

Q.15 (a)

Q.16 (d)

Q.17 (a)

L = 20 m; B = 10m; H = 3m

Q = 4 MLD = 4×10^6 lit/day

= 4×10^3 m³/day

$$V_0 = \frac{Q}{\text{B.L}} \frac{4 \times 10^6 \times 10^{-3}}{10 \times 20}$$

= 20 m³/m²/day

Q.18 (b)

For $\eta = 100\%$ VS = $V_0 = 20$ m/day

= 2.3148×10^{-4} m/sec

$$v = \frac{\mu}{\rho} \frac{1.002 \times 10^{-3}}{998.2}$$

= 1.0038×10^{-6} m²/sec

$$V_s = \frac{g}{18} (s - 1) \frac{d^2}{v}$$

2.3148×10^{-4}

$$= \frac{9.81}{18} (2.65 - 1) \frac{d^2}{1.0038 \times 10^{-6}}$$

d = 1.607×10^{-5} m

$$d = 16 \times 10^{-3} \text{ mm}$$

Q.19 (d)

Q = 28,800 m³/day = 20 m³/min

Volume (V) = Q × D_t = 20 × 2 = 40 m³

V = 10⁻⁶ m²/sec; ρ_w

= 1000 ks/m²

$$\therefore v = \frac{\mu}{\rho} \Rightarrow \mu = 10^{-6} \times 1000$$

$$= 10^{-3} \text{ N - sec/m}^2$$

$$\left(\frac{\text{m}^2}{\text{sec}} \times \frac{\text{kg}}{\text{m}^3} = \frac{\text{kg}}{\text{m-sec}} = \frac{\text{N-sec}}{\text{m}^2} \right)$$

Velocity gradient 'G' = 900 sec⁻¹

$$G = \sqrt{\frac{\text{Power(P)}}{\mu \text{Volume(V)}}} = \sqrt{\frac{P}{\mu V}}$$

$$900 = \sqrt{\frac{P}{10^{-3} \times 40}}$$

P = 32400 watts

Q.20 (d)

Q.21 (b)

Q = 4.2 m³/min

$V_0 = 0.2$ mm/s

$$= \frac{0.2}{1000} \times 60 = 0.612 \text{ m/min}$$

$$A = \frac{Q}{V_0} = 350 \text{ m}^2$$

Q.22 144 m³/day/m²

Q = 1m³/sec = 86400 m³/day

No. of filters = 14

Surface area of each filter = 50m²

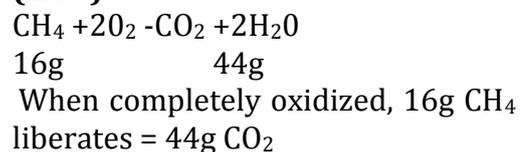
No. of filters in working condition = 14 - 2 = 12

Loading rate = $\frac{Q}{\text{surface area}}$

$$= \frac{86400}{12 \times 50} = 144 \text{ m}^3/\text{day}/\text{m}^2$$

Q.23 (b)

Q.24 (2.75)



$$\begin{aligned} \text{So, 1 kg. CH}_4 \text{ will liberate} &= \frac{44}{16} \times 1 \\ &= 2.75 \text{ kg} \end{aligned}$$

$$\begin{aligned} \Rightarrow d &= \sqrt{\frac{0.9 \times 40 \times 18 \times V \cdot \rho_w}{86480(G_s - 1) \times \rho_w \times g}} \\ \Rightarrow d &= 22.58 \mu\text{m} \end{aligned}$$

Q.25 (a)

For disinfection, we have $tc^n = K$
Where
t = time required to kill all organisms
c = concentration of disinfectant
n = dilution coefficient

k = constant

$$\text{So, } t_1 c_1^n = t_2 c_2^n$$

here, n=1

$$t_1 c_1 = t_2 c_2$$

$$t_1 = \frac{L}{V_1}; \quad L = \text{length of pipe}$$

V_1 = velocity of flow

$$= \frac{L}{Q_1/A} = \frac{L \cdot A}{Q_1}; \quad Q_1 = \text{discharge per}$$

day

$$C_1 = \frac{W_1}{Q_1}, \quad W_1 = \text{weight of disinfectant}$$

per day

$$\text{so, } \frac{LA}{Q_1} \cdot \frac{W_1}{Q_1} = \frac{LA}{Q_2} \cdot \frac{W_2}{Q_2}$$

$$\begin{aligned} W_2 &= \left(\frac{Q_2}{Q_1}\right)^2 \cdot W_1 = \left(\frac{22}{16}\right)^2 \times 32 \\ &= 60.5 \text{ kg/d} \end{aligned}$$

Q.26 (37800)

$$\begin{aligned} \text{Given } Q &= 35 \text{ m}^3 / \text{min} = 35 \times 10^3 \times 60 \\ &\times 24 \text{ l/day} \end{aligned}$$

$$\text{Alum dosage} = 25 \text{ mg/l}$$

Alum quantity required for 30 days

$$= 35 \times 10^3 \times 60 \times 24 \times 25 \times 10^{-6} \times 30$$

$$= 37800 \text{ kg.}$$

Q.27 22.58

$$\% \text{ removal} = \frac{V_s'}{V_s} \times 100$$

$$V_s' = 0.9 V_s$$

$$= \frac{0.9 \times 40}{86400} \text{ m/s}$$

$$\Rightarrow \frac{1}{18} \times d^2 \times \frac{g}{\mu} (\rho_s - \rho_w) = \frac{0.9 \times 40}{86400}$$

Q.28 (6.9)

Total area of settling tank required,

$$A = \frac{Q}{V} = 1500 = 75 \text{ m}^2$$

Since no. of tanks = 2

$$\text{So, area of each tank} = \frac{75}{2} = 37.5 \text{ m}^2$$

$$\frac{\pi d^2}{4} = 37.5 \Rightarrow d = 6.91 \text{ m}$$

4

WELL HYDRAULICS

Q.1 When there is an increase in the atmospheric pressure, the water level in a well penetrating in a confined aquifer

- a) increase
- b) decreases
- c) may increase or decrease depending on the nature of the aquifer
- d) does not undergo any change

[GATE 2004]

Q.2 Water is pumped from a well tapping an unconfined aquifer at a certain discharge rate any the steady state drawdown (X) in an observation well is monitored. Subsequently, the pumping discharge is doubled and the steady state drawdown in the same observation well is found to be more than double (i.e., more than 2X). This disproportionate drawdown is caused by

- a) well losses
- b) decrease in the saturated thickness of the aquifer
- c) nonlinear flow
- d) delayed gravity yield

[GATE-2003]

Q.3 Two observation wells penetrated into a confine: aquifer and located 1.5 km apart in the direction of flow, indicated head of 45 m and 20 m. If the coefficient of permeability of the aquifer is 30 m/day and porosity is 0.25, the time of trave of an inert tracer from one well to another is

- a) 416.7 days
- b) 500 days
- c) 750 days
- d) 3000 days

[GATE-2005]

Q.4 For steady flow to a fully penetrating well in a confined

aquifer, the draw downs at radial distances of r_1 and r_2 from the well have been measured as S_1 and S_2 respectively, for a pumping rate of Q . The transmissivity of the aquifer is equal to

- a) $\frac{Q}{2\pi} \left(\frac{\ln \frac{r_2}{r_1}}{S_1 - S_2} \right)$
- b) $\frac{Q}{2\pi} \frac{\ln(r_2 - r_1)}{(S_1 - S_2)}$
- c) $\frac{Q}{2\pi} \ln \left[\frac{r_2 / r_1}{S_1 / S_2} \right]$
- d) $2\pi Q \frac{r_2 - r_1}{\ln \left(\frac{S_2}{S_1} \right)}$

[GATE -2006]

Q.5 volume of $3.0 \times 10^6 \text{m}^3$ of groundwater was mped out from an unconfined aquifer uniformly om an area of 5 km². The pumping lowered the ,water table from initial level of 102 m to 99 m. The specific yield of the aquifer is

- a) 0.20
- b) 0.30
- c) 0.40
- d) 0.50

[GATE-2008]

Q.6 The relationship among specific yield (S_y), specific etention (S_r) and porosity (η) of an aquifer is

- a) $S_y = S_r + n$
- b) $S_y = S_r - n$
- c) $S_y = n - S_r$
- d) $S_y = S_r + 2n$

[GATE-2009]

Q.7 A well of diameter 20 cm fully penetrates a confined aquifer. After a long period of pumping at a rate of 2720 litres per minute, the observations of drawdown taken at 10 m and 100 m distances from the centre of the well are found to be 3 m and 0.5 m respectively. The transmissivity of the aquifer is

- a) 676 m²/day
- b) 576 m²/day
- c) 526 m²/day
- d) 249 m²/day

[GATE-2010]

Q.8 In an aquifer extending over 150 hectare, the water table was 20 m below ground level. Over a period of time the water table dropped to 23 m below the ground level. If the porosity of aquifer is 0.40 and the specific retention is 0.15, what is the change in ground water storage of the aquifer?

- a) 67,5 ha-m b) 112.5 ha-m
c) 180.0 ha-m d) 450.0 ha-m

[GATE-2011]

Q.9 The relationship between porosity (η), specific yield (S_y) and specific retention (S_r) of an unconfined aquifer is

- a) $S_y + S_r = \eta$ b) $S_y + \eta = S_r$
c) $S_r + \eta = S_y$ d) $S_y + S_r + \eta = 1$

[GATE-2015]

Q.10 A tracer takes 100 days to travel from Well-1 to Well-2 which are 100 m apart. The elevation of water surface in Well-2 is 3m below that in Well-1. Assuming porosity equal to 15%, the coefficient of permeability (expressed in m/day) is

- a) 0.30 b) 0.45
c) 1.00 d) 5.00

[GATE-2016]

Q.11 Water table of an aquifer drops by 100 cm over an area of 1000 km². The porosity and specific retention of the aquifer material are 25% and 5%, respectively. The amount of water (expressed in km³) drained out from the area is _____.

[GATE-2016]

ANSWER KEY:

| | | | | | | | | | | |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| (d) | (c) | (c) | (a) | (a) | (c) | (b) | (b) | (a) | (d) | 0.2 |

EXPLANATIONS

Q.1 (d)

Q.2 (c)

By Theim's formula, the discharge rate for an unconfined aquifer is given as

$$Q = \frac{\pi k (h_2^2 - h_1^2)}{2.3 \log_{10} \left(\frac{r_2}{r_1} \right)}$$

From the above formula it is obvious that pumping rate in a well in an unconfined aquifer follows nonlinear relationship with drawdown.

Q.3 (c)

The average flow velocity or discharge velocity,

$$v = ki = 30 \times \left(\frac{45 - 20}{1500} \right)$$

$$= 0.5 \text{ m/day}$$

Seepage velocity,

$$V_s \frac{v}{n} = \frac{0.5}{0.25} = 2 \text{ m/day}$$

$$\therefore \text{Travel time} = \frac{1500}{2} = 750 \text{ days}$$

Q.4 (a)

Q.5 (a)

Specific yield

$$\begin{aligned} & \frac{\text{Volume of water pumped out of the aquifer}}{\text{Total volume of aquifer}} \\ &= \frac{3.0 \times 10^6}{5 \times 10^6 \times (102 - 99)} = 0.20 \end{aligned}$$

Q.6 (c)

Q.7 (b)

$$Q = \frac{2\pi T (s_1 - s_2)}{\ln \left(\frac{r_2}{r_1} \right)}$$

Q.8 (b)

We know that

$$n = S_y + S_r$$

$$\Rightarrow S_y = S_r - n$$

$$= 0.15 - 0.40 = -0.25$$

The negative sign signifies the decrease in storage.

Change in volume of aquifer

$$= 150 \times (23 - 20) = 450 \text{ ha - m}$$

Specific yield is nothing but the actual volume of water that can be extracted by force of gravity from a unit volume of aquifer.

\therefore Change in water storage

$$= 450 \times 0.25 = 112.5 \text{ ha - m}$$

Q.9 (a)

Q.10 (d)

$$\text{Seepage velocity} = \frac{100}{100} = 1 \text{ m/day}$$

Discharge Velocity = $n \times$ seepage velocity = $0.15 \times 1 = 0.15 \text{ m/day}$

$$i = \frac{h}{L} = \frac{3}{100}$$

$$V = k \cdot i \Rightarrow 0.15 = k \times \frac{3}{100} \Rightarrow$$

$$k = 5 \text{ m/day}$$

Q.11 (0.2)

$$\Delta h = 100 \text{ cm}, A = 1000 \text{ km}^2$$

$$n = 0.25, r = 0.05$$

$$\therefore \text{Porosity} (\eta) = \text{Sp. yield} (y) + \text{Sp}$$

Retention (r)

$$\Rightarrow y = 0.25 - 0.05 = 0.20$$

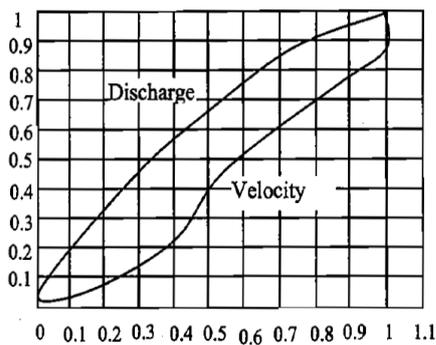
Amount of water drained out

$$= y \times A \times \Delta h = 0.2 \times 1000 \times 100 \times 10^{-5} = 0.2 \text{ km}^3$$

5

DESIGN OF SEWER

Q.1 An existing 300 mm diameter circular sewer is laid at a slop of 1:28 and carries a peak discharge of 1728 m³/d. Use the partial flow diagram shown in the figure below and assume Manning's n = 0.015. At the peak discharge, the depth of flow and the velocity are, respectively



Partial flow diagram for a circular sewer

- a) 45 mm and 0.28 m/s
- b) 120 mm and 0.50 m/s
- c) 150 mm and 0.57 m/s
- d) 300 mm and 0.71 m/s

[GATE-2004]

Q.2 Determine the correctness or otherwise of the following Assertion [a] and Reason [r]

Assertion [a]: The crown of the outgoing larger diameter sewer is always matched with the crown of incoming smaller diameter sewer.

Reason [r]: It elements backing up of sewage in the incoming smaller diameter sewer.

- a) Both [a] and [r] are true and [r] is the correct reason for [a]
- b) Both [a] and [r] are true and [r] is not the correct reason for [a]
- c) Both [a] and [r] are false
- d) [a] is true but [r] is false

[GATE-2008]

Q.3 Assertion (a): At a manhole, the crown of the outgoing sewer should not be higher than the crown of the incoming sewer.

Reason (r): Transition from a larger diameter incoming sewer to a smaller diameter outgoing sewer at a manhole should not be made.

The CORRECT option evaluating the above statements is:

- a) Both [a] and [r] are true and [r] is the correct reason for [a]
- b) Both [a] and [r] are true and [r] is not the correct reason for [a]
- c) Both [a] and [r] are false
- d) [a] is true but [r] is false

[GATE-2012]

Q.4 Crown corrosion in a reinforced concrete sewer is caused by:

- a) H₂S
- b) CO₂
- c) CH₄
- d) NH₃

[GATE-2016]

ANSWER KEY:

| | | | |
|----------|----------|----------|----------|
| 1 | 2 | 3 | 4 |
| (c) | (c) | (b) | (a) |

EXPLANATIONS

Q.1 (c)

$$D = 300 \text{ mm};$$

$$q = 1728 \text{ m}^3/\text{day};$$

$$n = 0.015; \quad S = 1/280$$

To find 'Q'

$$Q = A.V$$

$$= \frac{\pi}{4} . D^2 \times \frac{1}{n} . R^{2/3} . S^{1/2}$$

$$= \frac{\pi}{4} . (0.3)^2 \times \frac{1}{0.015} \times \left(\frac{0.3}{4}\right)^{2/3} \times \left(\frac{1}{280}\right)^{1/2}$$

$$= 0.05 \text{ m}^3/\text{sec}$$

$$= 4320 \text{ m}^3/\text{day}$$

$$\therefore \frac{q}{Q} = \frac{1728}{4320} = 0.4$$

For $\frac{q}{Q} = 0.4$; from the graph (given)

$$\frac{d}{D} = 0.5$$

For $\frac{d}{D} = 0.5$, the $\frac{\vartheta}{V} = 0.8$

$$\therefore \frac{d}{D} = 0.5$$

$$\Rightarrow d = 0.5 \times 0.3 = 150 \text{ mm}$$

$$\therefore \frac{\vartheta}{V} = 0.8$$

$$\vartheta = 0.8 \times 0.708 = 0.57 \text{ m/sec}$$

Q.2 (c)

Q.3 (b)

Q.4 (a)

6

QUALITY AND CHARACTERISTICS OF SEWAGE

Q.1 Critical factors for the activated sludge treatment process are
 a) maximum hourly flow rate
 b) maximum and minimum flow rate
 c) maximum hourly flow rate and maximum daily organic load.
 d) maximum hourly flow rate minimum daily organic load.

[GATE - 2000]

Q.2 The BOD removal efficiency, in percentage, during primary treatment, under normal condition is about.

- a) 65%
- b) 85%
- c) 30%
- d) zero

[GATE-2000]

Q.3 If the BOD_{5,20} of waste is 150 mg/L and the reaction rate constant (to the best 'e') at 20°C is 0.35/day, the ultimate BOD in mg/L is

- a) 97.5
- b) 181.5
- c) 212.5
- d) 230.5

[GATE-2001]

Q.4 A waste water sample has an initial BOD of 222 mg/L. The first order BOD decay coefficient is 0.4/days. The BOD consumed (in mg/l) in 5 day is

- a) 150
- b) 192
- c) 30
- d) 50

[GATE-2002]

Q.5 A trickling filter is designed to remove

- a) Settle able Solids
- b) Colloidal Solids
- c) Dissolved Organic Matter
- d) None of the above

[GATE - 2002]

Q.6 In a domestic wastewater sample, COD and BOD were measured.

Generally which of the following statement is true for their relative magnitude?

- a) COD = BOD
- b) COD > BOD
- c) COD < BOD
- d) Nothing can be said

[GATE-2002]

Q.7 Settling test on a sample drawn from aeration Tank liquor of ASP (MLSS = 2800 mg/l) was carried out with 1litre sample . The test yielded a settled volume of 200 ml. The value of sludge volume index shall be

- a) 14.0
- b) 34.2
- c) 71.4
- d) 271

[GATE - 2003]

Q.8 A portion of waste water sample was subjected to standard BOD test (5 days, 20°C), yielding a value of 180 mg/L. The reaction rate constant (to the base 'e') at 20°C was taken as 0.18 per day. The reaction rate constant at other temperature may be estimated by $k_T = k_{20} (1.047)^{T-20}$. The temperature at which the other portion of the sample should be tested, to exert the same BOD in 2.5 days, is

- a) 4.9°C
- b) 24.9°C
- c) 31.7°C
- d) 35.0°C

[GATE-2004]

Q.9 In aerobic environment, nitrosomonas convert

- a) NH₃ to NO₂
- b) NO₂ to NO₃
- c) NH₃ to N₂O
- d) NO₂ to HNO₃

[GATE - 2005]

Q.10 Group I contains some properties of water/wastewater and group II contains list of some tests on

water/waste water. Match the property with corresponding test.

Group I

- P. Suspended solids concentration
- Q. Metabolism of biodegradable organics
- R. Bacterial concentration
- S. Coagulant does

Group II

- 1. BOD
- 2. MPN
- 3. Jar test
- 4. Turbidity

Codes:

| | P | Q | R | S |
|----|---|---|---|---|
| a) | 2 | 1 | 4 | 3 |
| b) | 4 | 1 | 2 | 3 |
| c) | 2 | 4 | 1 | 3 |
| d) | 4 | 2 | 1 | 3 |

[GATE-2005]

Q.11 The composition of a certain MSW sample and specific weights of its various components given below:

| Component | Percent by weight | Specific weight (kg/m ³) |
|---------------------|-------------------|--------------------------------------|
| Food waste | 50 | 300 |
| Dirt and ash | 30 | 500 |
| Plastics | 10 | 65 |
| Wood and Yard waste | 10 | 125 |

Specific weight (kg/m³) of the MSW sample is

- a) 319
- b) 217
- c) 209
- d) 199

[GATE - 2006]

Q.12 To determinate the BODs of a waste water sample, 5, 10 and 50 mL aliquots of the wastewater were diluted to 300mL and incubate at 20°C in BOD bottles for 5 days.

The results were as follows.

| Sr.No. | Waste water Volume, ml | Initial DO mg/l | DO after 5 days, mg/l |
|--------|------------------------|-----------------|-----------------------|
| 1 | 5 | 9.2 | 6.9 |
| 2 | 10 | 9.1 | 4.4 |
| 3 | 50 | 8.4 | 0.0 |

Based on the data, the average BODs of the wastewater is equal to

- a) 139.5 mg/L
- b) 126.5 mg/L

- c) 109.8 mg/L
- d) 72.2 mg/L

[GATE-2006]

Q.13 The 5-day BOD of a wastewater sample is obtained as 190mg/l (with $k = 0.01h^{-1}$). The ultimate oxygen demand (mg/l) of the sample will be

- a) 3800
- b) 475
- c) 271
- d) 190

[GATE-2008]

Q.14 A horizontal flow primary clarifier treats wastewater in which 10%, 60%, and 30% of particles have settling velocities of 0.1 mm/s, 0.2 mm/s, and 1.0 mm/s respectively. What would be the total percentage of particles removed if clarifier operates at a Surface Overflow Rate (SOR) of 43.2 m³/d/m²?

- a) 43%
- b) 56%
- c) 86%
- d) 100%

[GATE-2009]

Q.15 If the BOD₃ of a wastewater sample is 75 mg/L and reaction rate constant k (base e) is 0.345 per day, the amount of BOD remaining in the given sample after 10 days is

- a) 3.21mg/L
- b) 3.45mg/L
- c) 3.69mg/L
- d) 3.92mg/L

[GATE-2010]

Q.16 A student began experiment for determination of 5-day 20°C BOD on Monday. Since the 5th day fell on Saturday, the final DO readings were taken on next Monday. On calculation, BOD (i.e. 7 day, 20°C) was found to be 150 mg/L. What would be the 5-dy, 20°C BOD (in mg/L)? Assume values of BOD rate constant (k) at standard temperature of 20°C as 0.23/day (base e).

[GATE-2013]

Q.17 Total Kjeldahl Nitrogen (TKN) concentration (mg/L as N) in

domestic sewage is the sum of the concentrations of:

- a) organic and inorganic nitrogen in sewage
- b) organic nitrogen and nitrate in sewage
- c) organic nitrogen and ammonia in sewage
- d) ammonia and nitrate in sewage

[GATE-2015]

Q.18 Ultimate BOD of a river water sample is 20 mg/L. BOD rate constant (natural log) is 0.15 day^{-1} . The respective values of BOD (in %) exerted and remaining after 7 days are:

- a) 45 and 55
- b) 55 and 45
- c) 65 and 35
- d) 75 and 25

[GATE-2015]

Q.19 Effluent from an industry 'A' has a pH of 4.2. The effluent from another industry 'B' has double the hydroxyl (OH^-) ion concentration than the effluent from industry 'A'. pH of effluent from the industry 'B' will be

—

[GATE-2016]

Q.20 The 2-day and 4-day BOD values of a sewage sample are 100 mg/L and 155 mg/L, respectively. The value of BOD rate constant (expressed in per day) is _____.

[GATE-2016]

Q.21 For a wastewater sample, the three-day biochemical oxygen demand at incubation temperature of 20°C ($\text{BOD}_{3\text{day}, 20^\circ\text{C}}$) is estimated as 200 mg/L. Taking the value of the first order BOD reaction rate constant as 0.22 day^{-1} , the five-day BOD (expressed in mg/L) of the wastewater at incubation temperature of 20°C ($\text{BOD}_{5\text{day}, 20^\circ\text{C}}$) would be _____

[GATE-2016]

ANSWER KEY:

| | | | | | | | | | | | | | |
|-----------|-----------|-----------|-----------|-----------|-----------|-----------|----------|----------|-----------|-----------|-----------|-----------|-----------|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| (c) | (c) | (b) | (b) | (c) | (b) | (c) | (d) | (a) | (b) | (b) | (a) | (c) | (b) |
| 15 | 16 | 17 | 18 | 19 | 20 | 21 | | | | | | | |
| (c) | * | (c) | (c) | 4.5 | 0.3 | 276 | | | | | | | |

EXPLANATIONS

Q.1 (c)

$$\Rightarrow T - 20 = 15.09$$

$$T = 15.09 + 20 = 35.09^\circ\text{C} = 35^\circ\text{C}$$

Q.2 (c)

Q.3 (b)

$$150 = L_0[1 - e^{-0.35 \times 5}]$$

$$\therefore L_0 = 181.5 \text{ mg/lit}$$

Q.4 (b)

$$\text{BOD} = 222[1 - e^{-0.4 \times 5}]$$

$$\therefore \text{BOD} = 192 \text{ mg/lit}$$

Q.5 (c)

Q.6 (b)

Q.7 (c)

$$X_t = 2800 \text{ mg/lit}$$

$$V_s = 200 \text{ ml}$$

$$\text{SVI} = \frac{V_s}{\left(\frac{X_t}{1000}\right)} = \frac{200}{2.8} = 71.42 \text{ ml/gm}$$

Q.8 (d)

$$Y_5^{20^\circ} = 180 \text{ mg/1K}_{20} = 0.18 \text{ d}^{-1}$$

$$Y_{2.5}^{T^\circ\text{C}} = 180 \Rightarrow T^\circ\text{C} = ?$$

$$Y_5^{20^\circ} = Y_{2.5}^T = 180$$

$$Y_5^{20^\circ} = L_0[1 - e^{-Kt}]$$

$$L_0 = \frac{Y_5^{20^\circ}}{L_0[1 - e^{-Kt}]} = \frac{Y_{2.5}^T}{L_0[1 - e^{-Kt}]}$$

$$180 = L_0[1 - e^{-K_{20} \times 5}] = L_0[1 - e^{-K_{20} \times 5}]$$

$$-K_{20} \times 5 = -K_T \times 2.5$$

$$0.18 \times 5 = K_{20}(1.047) \times 2.5$$

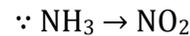
$$0.18 \times 5 = 0.18 [1.047]^{T-20} \times 2.5$$

$$[1.047]^{T-20} = \frac{5}{2.5} = 2$$

$$(T - 20) \ln [1.047] = \ln(2)$$

Q.9 (a)

In aerobic environment well oxidized sewage contain nitrogen in the form of nitrates.



Q.10 (b)

Suspended solids concentration \rightarrow Turbidity

Metabolism of biodegradable organic \rightarrow BoD

Bacterial concentration \rightarrow MPN

Coagulant dose \rightarrow Jar test

Q.11 (b)

$$\text{Specific weight} = \frac{\text{weight}}{\text{volume}}$$

$$\gamma = W/V$$

Let us take a weight, weight of 100 kg of MSW

| Component | Weight | Volume |
|-------------------|--------|--------------------------------------|
| Food waste | 50 Kg | $\frac{50}{300} = 0.167 \text{ m}^3$ |
| Dust & Ash | 30 Kg | $\frac{30}{300} = 0.06 \text{ m}^3$ |
| Plastics | 10 Kg | $\frac{10}{65} = 0.154 \text{ m}^3$ |
| Wood & Yard Waste | 10 Kg | $\frac{10}{125} = 0.08 \text{ m}^3$ |

Total avg.

$$\gamma = \frac{W}{V} = \frac{100}{0.461} = 217 \text{ kg/m}$$

Q.12 (a)

| S. No. | Waste Water volume mL | Initial D.O. mg/l | Final D.O. mg/l | BoD ₅ ^{20°} = [D.O. _i - D.O. _f] × D.F |
|--------|-----------------------|-------------------|-----------------|--|
| 1 | 5 | 9.2 | 6.9 | $= \frac{(9.2-6.9) \times 300}{5} = 138$ |
| 2 | 10 | 9.1 | 4.4 | $= \frac{(9.1-4.4) \times 300}{10} = 141$ |
| 3 | 50 | 8.4 | 0.0 | =0 |

$$\therefore \text{BoD}_{5\text{avg}} = \frac{138 + 141}{2} = 139.5$$

Q.13 (c)

$$\begin{aligned} K &= 0.01 \text{ / hr} \\ &= 0.01 \times 24 = 0.24/\text{day} \\ \text{BOD}_5 &= L(1 - e^{-k \cdot 5}) \\ 190 &= L(1 - e^{-0.24 \times 5}) \\ L &= 271 \text{ mg/lt} \\ \text{BOD}_u &= L = 271 \text{ mg/lit} \end{aligned}$$

Q.14 (b)

$$\begin{aligned} V_0 &= 43.2 \text{ m/day} = \frac{43.2 \times 10^3}{24 \times 60 \times 60} \\ &= 0.5 \text{ mm/sec} \\ V_{s1} &= 0.1 \text{ mm/sec;} \\ \text{for } \eta_1 &= \frac{V_s}{V_0} \times 100 = \frac{0.1}{0.5} \times 100 = 20\% \\ V_{s2} &= 0.2 \text{ mm/sec;} \\ \text{For } \eta_2 &= \frac{V_{s2}}{V_0} \times 100 = 40\% \\ V_{s2} &= 1 \text{ mm/sec; for } \eta_3 = 100\% \\ \% \text{ particle removed in total} \\ \text{(overall efficiency)} \\ \eta &= \frac{(0.20 \times 0.10) + (0.40 \times 0.60) + (1 \times 0.3)}{0.1 + 0.6 + 0.3} \\ &= 0.56 = 56\% \end{aligned}$$

Q.15 (c)

$$\begin{aligned} L_t &= L \cdot e^{-kt} \\ L_{10} &= L \cdot e^{-k \times 10} \\ &= 3.69 \text{ mg/lit} \end{aligned}$$

Q.16 128.112 mg/l

$$\begin{aligned} Y_7^{20^\circ C} &= 150 = L_0[1 - e^{-k_{20} \times 7}] \\ 150 &= L_0[1 - e^{-0.23 \times 7}] \\ \Rightarrow L_0 &= 187.473 \text{ mg/l} \\ Y_5^{20^\circ C} &= L_0[1 - e^{-k_{20} \times 5}] \\ &= 187.473[1 - e^{-0.23 \times 5}] \\ &= 128.112 \text{ mg/l} \end{aligned}$$

Q.17 (c)

Total Kjeldahl Nitrogen (TKN) = Ammonia (60%) + Organic Nitrogen (40%)

Q.18 (c)

$$\begin{aligned} y_u &= 20 \text{ mg/L} \\ \text{After 7 days} &= y_u e^{-kt} \\ &= 20 \times e^{0.15 \times 7} = 7 \\ \% \text{ is} &= \frac{7}{20} = 35\% \\ \text{exerted} &= 100 - 35 = 65\% \end{aligned}$$

Q.19 (4.5)

$$\begin{aligned} \text{A} \\ \text{pH} &= 4.2, \text{pOH} = 9.8 \\ \Rightarrow [\text{OH}^-] &= 10^{-9.8} \text{ mol/L} \\ \text{B} \\ [\text{OH}^-] &= 2 \times 10^{-9.8} \text{ mol/L} \\ \Rightarrow \text{pOH} &= 9.8 - \log_{10} 2 = 9.5 \\ \Rightarrow \text{pH} &= 4.5 \end{aligned}$$

Q.20 (0.3)

$$\begin{aligned} \text{BOD}_2 &= L_0 \times (1 - e^{-k \times 2}) \\ \Rightarrow 100 &= L_0 \times (1 - e^{-2k}) \quad \dots(i) \\ \text{Also,} \\ 155 &= L_0 \times (1 - e^{-4k}) \quad \dots(ii) \\ (i) / (ii) \\ \Rightarrow \frac{100}{155} &= \frac{1 - e^{-2k}}{1 - e^{-4k}} \\ \Rightarrow 1 - e^{-4k} &= 1.55 - 1.55 \times e^{-2k} \\ \Rightarrow e^{-4k} - 1.55 \times e^{-2k} + 0.55 &= 0 \\ \text{Let } e^{-2k} &= x \\ \Rightarrow x^2 - 1.55x + 0.55 &= 0 \end{aligned}$$

$$\Rightarrow x = 0.55$$

$$e^{-2k} = -0.55 \Rightarrow k = 0.3 \text{ day}^{-1}$$

Q.21 (276.158)

Given

$$(\text{BOD})_3 = 200 \text{ mg/L}$$

$$k_D = 0.22/\text{day}$$

$$(\text{BOD})_5 = ?$$

$$(\text{BOD})_3 = L_0 (1 - e^{-k_D t})$$

$$200 = L_0 (1 - e^{-0.22 \times 3})$$

$$L_0 = \frac{200}{1 - e^{-0.66}} = \frac{200}{0.483} = 413.95$$

$$(\text{BOD})_5 = L_0 (1 - e^{-k_D t})$$

$$= 413.95 (1 - e^{-0.22 \times 5})$$

$$= 276.158 \text{ mg/L}$$

7

DISPOSING OF THE SEWAGE EFFLUENTS

Q.1 The unit in which both sedimentation and digestion processes of sludge take place simultaneously is
 a) Skimming tank b) Imhoff Tank
 c) Detritus Tank d) Digestion Tank

[GATE - 2001]

Q.2 Match the following:

Group I

(Characteristics of sewage Discharged into inland waters)

P. BOD₅

Q. COD

R. Oil and Grease

S. Total Suspended Solids

Group II (Allowable limit,mg/l)

1. 250

2. 30

3. 20

4. 10

5. 5

6. 3

Codes:

| | P | Q | R | S |
|----|---|---|---|---|
| a) | 2 | 5 | 4 | 2 |
| b) | 4 | 1 | 6 | 4 |
| c) | 3 | 1 | 4 | 2 |
| d) | 2 | 1 | 6 | 3 |

[GATE-2003]

Q.3 In a certain situation, wastewater discharged into a river, mixes with the river water instantaneously and completely. Following is the data available:

Wastewater: DO = 2.00 mg/L

Discharge rate = 1.10 m³/s

River water DO = 8.3 mg/L

Flow rate = 8.70 m³/s

Temperature = 20°C

Initial amount of DO in the mixture of waste and river shall be

a) 5.3 mg/L b) 6.5 mg/L

c) 7.6 mg/L d) 8.4 mg/L

[GATE - 2005]

Q.4 A landfill is to be designed to serve a population of 200000 for a period of 25 years. The solid waste (SW) generation is 2 kg/person/day. The density of the un-compacted SW is 100 kg/m³ and a compaction ratio of 4 is suggested. The ratio of compacted fill (i.e. SW + cover) to compacted SW is 1.5. The landfill volume (in million m³) required is __

[GATE - 2015]

ANSWER KEY:

| 1 | 2 | 3 | 4 |
|-----|-----|-----|------|
| (b) | (c) | (c) | 21.9 |

EXPLANATIONS

Q.1 (b)

Q.2 (c)

Q.3 (c)

Waste water River water

$$DO = 2 \text{ mg/lit}$$

$$DO_R = 8.3 \text{ mg/wt}$$

$$A_s = 1.1 \text{ m}^3/\text{sec}$$

$$A_R = 8.7 \text{ m}^3/\text{sec}$$

$$DO_m = \frac{A_s \times DO_s + A_R \times DO_R}{A_s + A_R}$$

$$= \frac{1.1 \times 2 + 8.7 \times 8.3}{1.1 + 8.7}$$

$$= 7.59 \approx 7.6 \text{ mg/lit}$$

Q.4 (21.9)

Total solid waste generated

$$= 2 \text{ kg} \times 2 \times 10^5 = 400000 \text{ kg/day}$$

$$\text{For 25 years} = 400000 \times 365 \times 25$$

$$= 3.65 \times 10^9 \text{ kg}$$

compaction ratio =

$$\frac{\text{volume after compaction}}{\text{volume before compaction}}$$

$$V = \frac{3.65 \times 10^9}{100} = 3.65 \times 10^7 \text{ m}^3$$

$$V' = 0.4 \times 3.65 \times 10^7 = 1.46 \times 10^7 \text{ m}^3$$

$$\frac{\text{sw} + \text{cover}}{\text{sw}} = \frac{\text{sw}}{\text{sw}} + \frac{\text{cover}}{\text{sw}} = 1.5$$

$$\Rightarrow \frac{\text{cover}}{\text{sw}} = 0.5$$

$$\Rightarrow \text{cover} = 0.5 \times 1.46 \times 10^7 = 0.73 \times 10^7 \text{ m}^3$$

$$\text{Total volume} = (1.46 + 0.73 \times 10^7)$$

$$= 21.9 \times 10^6 \text{ m}^3$$

$$= 21.9 \text{ million m}^3$$

8

TREATMENT OF SEWAGE

- Q.1** From amongst the following sewage treatment options, largest land requirements for a given discharge will be needed for
- trickling filter
 - anaerobic pond
 - oxidation ditch
 - oxidation pond

[GATE - 2003]

- Q.2** Which of the following sewage treatment methods has inherent problems of odour? ponding, and fly nuisance?
- USAB system
 - Activated sludge process
 - Trickling filters
 - Stabilization ponds

[GATE - 2003]

- Q.3** The following data are given for a channel-type grit chamber of length 7.5m.

- Flow-through velocity = 0.3 m/s
- The depth of wastewater at peak flow in the channel = 0.9 m
- Specific gravity of inorganic particles = 2.5
- $g = 9.80 \text{ m/s}^2$ $m = 1.002 \times 10^{-3} \text{ N-s/m}^2$

at 20°C, $p_w = 1000 \text{ kg/m}^3$

Assuming that the Stokes law is valid, the largest diameter particle that would be

Removed with 100 percent efficiency is

- 0.04 mm
- 0.21 mm
- 1.92 mm
- 6.64 mm

[GATE - 2004]

- Q.4** An analysis for determination of solids in the return sludge of activated sludge process was done as follows:

- A crucible was dried to a constant mass of 62.485 g.

- 75mL of a well-mixed sample was taken in the crucible
- The crucible with the sample was dried to a constant mass of 65.020g in a drying oven at 104°C
- The crucible with the dried sample was placed in a muffle furnace at 6000C, for an hour. After cooling, the mass of the crucible with residues was 63.145 g,

The concentration of organic fraction of solids present in a return sludge sample is

- 8800 mg/L
- 25000 mg/L
- 33800 mg/L
- 42600 mg/L

[GATE - 2004]

- Q.5** Match the following :

Group I

- Thickening sludge
- Stabilization of sludge
- Conditioning of sludge
- Reduction of sludge

Group II

- Decrease in volume of sludge by Chemical
- Separation of water by heat or Chemical treatment
- Digestion of sludge
- Separation of water by flotation or Gravity

Codes :

| | P | Q | R | S |
|----|---|---|---|---|
| a) | 4 | 3 | 1 | 2 |
| b) | 3 | 2 | 4 | 1 |
| c) | 4 | 3 | 2 | 1 |
| d) | 2 | 1 | 3 | 4 |

[GATE-2005]

- Q.6** Bulking sludge refers to having

- $F/M < 0.3 \text{ d}$
- $0.3/\text{d} F/M < 0.6/\text{d}$
- $F/M = \text{zero}$
- $F/M > 0.6/\text{d}$

[GATE - 2005]

Common Data for Que.7 and 8:

A completely mixed activated sludge process is used to treat a wastewater flow of 1 million liters per day (1MLD) having a BOD₅ of 200mg/L. The biomass concentration in the aeration tank is 2000 mg/L and the concentration of the net biomass leaving the system of 50 mg/L the aeration tank has a volume of 200 m³.

Q.7 What is the hydraulic retention time of a wastewater in aeration tank?
 a) 0.2 h b) 4.8 h
 c) 10 h d) 24 h
[GATE -2007]

Q.8 What is the average time for which the biomass stays in the system?
 a) 5h b) 8h
 c) 2 days d) 8 days
[GATE -2007]

Q.9 Match Group I (Terminology) with Group-II (Definition / Brief Description) for wastewater treatment systems.

Group I

- P. Primary treatment
- Q. Secondary treatment
- R. Unit operation
- S. Unit process

Group II

- 1. Contaminant removal by physical forces
- 2. Involving biological and/or chemical reaction
- 3. Conversion of soluble organic matter to biomass
- 4. Removal of solid material from incoming waste water

Codes:

- a) P-4, Q-3, R-1, S-2
- b) P-4, Q-3, R-2, S-1
- c) P-3, Q-4, R-2, S-1
- d) P-1, Q-2, R-3, S-4

[GATE-2008]

Q.10 A aerobic reactor receives wastewater at a flow rate of 500

m³/d having a COD of 2000 mg/L. The effluent COD is 400 mg/L. Assuming the wastewater contains 80% biodegradable waste, the daily volume of methane produced by the reactor is

- a) 0.224 m³ b) 0.280 m³
- c) 244 m³ d) 280 m³

[GATE - 2009]

Q.11 Column I

- P. Grit chamber
- Q. Secondary settling tank
- R. Activated sludge process
- S. Trickling filter

Column II

- 1. Zone settling
- 2. Stoke's law
- 3. Aerobic
- 4. Contact stabilization

The correct match of **Column I** with **Column II** is

- a) P - 1, Q - 2, R - 3, S - 4
- b) P - 2, Q - 1, R - 3, S - 4
- c) P - 1, Q - 2, R - 4, S - 3
- d) P - 2, Q - 1, R - 4, S - 3

[GATE - 2009]

Statement for linked question 12 or 13:

The sludge from the aeration tank of the activated sludge process (ASP) has solids content (by Weight) of 2%, This sludge is put in a sludge thickener, where sludge volume is reduced to half. Assume that the amount of solids in the supernatant from the thickener is negligible, the specific gravity of sludge solids is 2.2 and the density of water is 1000 kg/m³.

Q.12 What is the density of the sludge removed from the aeration tank?

- a) 990 kg/m³ b) 1000kg/m³
- c) 1011 kg/m³ d) 1022 kg/m³

[GATE-2011]

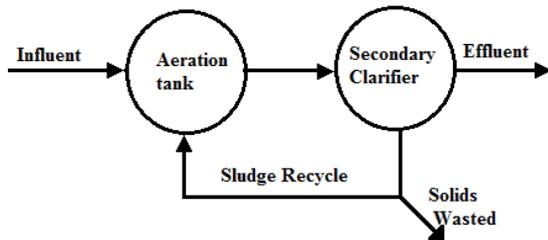
Q.13 What is the solids content (by weight) of the thickened sludge?

- a) 3.96% b) 4.00%
- c) 4.04% d) 4.10%

[GATE-2011]

Common data for questions 14 and 15:

An activated sludge system (sketched below) is operating at equilibrium with the following information Wastewater related data:



Flow rate = 500 m³/hour, influent BOD = 150 mg/L. effluent BOD = 10 mg/L. Aeration Tank related data: hydraulic retention time = 8 hours, mean-cell-residence time = 240 hours, volume = 4000 m³, mixed liquor suspended solids = 2000 mg/L

Q.14 The food-to-biomass (F/M) ratio (in kg BOD per kg biomass per day) for the aeration tank is

- a) 0.015
- b) 0.210
- c) 0.225
- d) 0.240

[GATE -2012]

Q.15 The mass (n kg/day) of solids wasted from the system is

- a) 24000
- b) 1000
- c) 800
- d) 33

[GATE -2012]

Q.16 A sample of domestic sewage is digested with silver sulphate, sulphuric acid, potassium dichromate and mercuric sulphate in chemical oxygen demand (COD) test. The digest sample is then titrated with standard ferrous ammonium sulphate (FAS) to determine the un-reached amount of

- a) mercuric sulphate
- b) potassium dichromate
- c) silver sulphate
- d) sulphuric acid

[GATE-2012]

Q.17 A settling tank in a water treatment plant is designed for a surface

overflow rate of 30 m³/day.m². Assume specific gravity of sediment particles = 2.65, density of water (ρ) = 1000 Kg/m³, dynamic viscosity of water (μ) = 0.001 N.s/m², and Stokes' law is valid. The approximate minimum size of particles that would be completely removed is:

- a) 0.01 mm
- b) 0.02 mm
- c) 0.03 mm
- d) 0.04 mm

[GATE-2013]

Q.18 The dominating microorganisms in an activated sludge process reactor are

- a) aerobic heterotrophs
- b) anaerobic heterotrophs
- c) autotrophs
- d) phototrophs

[GATE -2014]

Q.19 A waste water stream (flow = 2 m³/s, ultimate BOD = 90 mg/l) is joining a small river (flow = 12 m³/s, ultimate BOD = 5 mg/l). Both water streams get mixed up instantaneously. Cross-sectional area of the river is 50 m². Assuming the de-oxygenation rate constant, k = 0.25/day, the BOD (in mg/l) of the river water, 10 km downstream of the mixing point is

- a) 1.68
- b) 12.63
- c) 15.46
- d) 1.37

[GATE -2014]

Q.20 Solid waste generated from an industry contains only two components, X and Y as shown in the table below

| Component | Composition (% weight) | Density (kg/m ³) |
|-----------|------------------------|------------------------------|
| X | c ₁ | ρ_1 |
| Y | c ₂ | ρ_2 |

Assuming $(c_1+c_2) = 100$, the composite density of the solid waste (ρ) is given by:

a) $\frac{100}{\left(\frac{C_1}{\rho_1} + \frac{C_2}{\rho_2}\right)}$ b) $100 \left(\frac{\rho_1}{C_1} + \frac{\rho_2}{C_2}\right)$
 c) $100(c_1\rho_1 + c_2\rho_2)$ d) $N77^\circ50'E$
[GATE -2015]

Q.21 In a wastewater treatment plant, primary sedimentation tank (PST) designed at an overflow rate of $32.5 \text{ m}^3/\text{day}/\text{m}^2$ is 32.5 m long, 80 m wide and liquid depth of 2.25 m . If the length of the weir is 75 m , the weir loading rate (in $\text{m}^3/\text{day}/\text{m}$) is _____
[GATE -2015]

Q.22 Match the items in Group — I with those in Group — II and choose the right combination.

Group - I

- P. Activated sludge process
- Q. Rising of sludge
- R. Conventional nitrification
- S. Biological nitrogen removal

Group - II

1. Nitrifiers and denitrifiers
2. Autotrophic bacteria
3. Heterotrophic bacteria
4. Denitrifiers

- a) P-3, Q-4, R-2, S-1 b) P-2, Q- 3, R-4, S-1
 c) P-3, Q-2, R-4, S-1 d) P-1, Q-4, R-2, S-3

[GATE -2016]

ANSWER KEY:

| | | | | | | | | | | | | | |
|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|----------|-----------|-----------|-----------|-----------|-----------|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| (d) | (c) | (b) | (b) | (c) | (a) | (b) | (d) | (a) | (d) | (d) | (c) | (b) | (c) |
| 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | | | | | | |
| (c) | (b) | (b) | (a) | (c) | (a) | * | (a) | | | | | | |

EXPLANATIONS

Q.1 (d)

Q.2 (c)

Q.3 (b)

$$L = 7.5$$

$$V_H = 0.3 \text{ m/sec}$$

$$H = 0.9 \text{ m}$$

$$V = \frac{\mu}{\rho} = \frac{1.002 \times 10^{-3}}{1000}$$

$$= 1.002 \times 10^{-6} \text{ m}^2/\text{sec}$$

$$\text{For } \eta = 100\%, \frac{L}{V_H} = \frac{L}{V_S}$$

$$\Rightarrow V_S = \frac{g}{18} \left(s - 1 \cdot \frac{d^2}{v} \right)$$

$$0.036 = \frac{9.8}{18} (2.5 - 1) \cdot \frac{d^2}{(1.002 \times 10^{-6})}$$

$$d = 0.21 \text{ mm}$$

Q.4 (b)

Initial weight empty dry crucible

$$= 62.485 \text{ gm}$$

Volume of sample tested = 75 ml.

Upon oven drying @ 104°C the weight of crucible

$$= 65.020 \text{ gm}$$

Total solids in sample

$$= \frac{W_{\text{final}} - W_{\text{initial}}}{\text{volume of sample test}}$$

$$= \frac{65.020 - 62.485}{75} \times 10^6 = 33800 \text{ mg/l}$$

To find organic fraction:

After keeping in muffle furnace final

Weight = 63.145 gm

∴ Inorganic in sample

$$= \frac{63.145 - 62.485}{75} \times 10^6$$

$$= 8800 \text{ mg/l}$$

Organic fraction

$$= \text{Total solids} - \text{Inorganic fraction}$$

$$= 33800 - 8800 = 25000 \text{ mg/l}$$

Q.5 (c)

Stabilization of sludge means

Digestion of sludge

Reduction of sludge

Decrease in volume of sludge by chemical oxidation

Q.6 (a)

Q.7 (b)

$$Q = 1 \times 10^6 \text{ lit/day}$$

$$y_i = 200 \text{ mg/lit}$$

$$X_f = 2000 \text{ mg/lit}$$

$$X_e = 50 \text{ mg/lit}$$

$$V = 200 \text{ m}^3 = 200 \times 10^3 \text{ lit}$$

$$\text{HRT} = \frac{V}{Q} = \frac{200 \times 10^3}{1 \times 10^6}$$

$$= 0.2 \text{ days} = 4.8 \text{ hours}$$

Q.8 (d)

$$\theta_c = \frac{V \times X}{Q_w \times X_w + Q_e \times X_e}$$

Neglecting

θ_w (being small & not given)

$$\theta = \theta_e$$

$$\therefore \theta_c = \frac{200 \times 10^3 \times 2000}{1 \times 10^6 \times 50} = 8 \text{ days}$$

Q.9 (a)

Q.10 (d)

$$Q = 500 \text{ m}^3/\text{day} = 0.5 \text{ MLD}$$

Influent COD: 2000 mg/l

Effluent COD: 400 mg/l

COD removed = 2000 - 400

$$= 1600 \text{ mg/l}$$

Biodegrades in COD = 1600 × 0.8

$$= 1280 \text{ mg/l}$$

$$\text{VSS in Biodegrades} = 1280 \times \frac{70}{100}$$

$$= 896 \text{ (Assumed 70\% Volatiles)}$$

Total Volatiles in waste water flow
 $= Q \times VSS = 0.5 \times 896 = 448 \text{ kg/day}$
 Gas produced @ $0.9 \text{ m}^3/\text{kg}$ of VSS
 $= 0.9 \times 448 = 403.2 \text{ m}^3$
 Methane gas = 70% of the total gas
 $= 403.2 \times 0.7 = 282.25 \text{ m}^3 = 280 \text{ m}^3$

$$\left(\frac{240}{24}\right) = \frac{(400 \times 10^3) 2000}{Q_w \cdot X_w}$$

Mass of solids, $Q_w X_w$
 $= 800 \times 10^6 \text{ mg/day}$
 $= 800 \text{ kg/day}$

Q.11 (d)

Q.12 (c)

Solid content = 2%

\therefore Water content = 98%

$$\frac{100}{S_{\text{sludge}}} = \frac{\% \text{water}}{S_{\text{water}}} + \frac{\% \text{Solids}}{S_{\text{solids}}}$$

$$\frac{100}{S_{\text{sludge}}} = \frac{98}{1} + \frac{2}{2.2}$$

$$S_{\text{sludge}} = 1.011$$

$$S_{\text{sludge}} = 1.011 \times 100 = 1011 \text{ kg/m}^3$$

Q.13 (b)

After thickening $V_2 = \frac{V_1}{2}$

$$\therefore V_2 = \frac{(100 - P_1) \cdot V_1}{(100 - P_2)}$$

$$\therefore 100 - P_2 = 200 - 196$$

$$\therefore P_2 = 96\%$$

\therefore Solid content is 4%

Q.14 (c)

$$\frac{F}{M} = \frac{Q \cdot y_i}{V \cdot X_t}$$

$$= \frac{500 \times 10^3 \times 24 \times 150}{4000 \times 10^3 \times 2000}$$

$$= 0.225$$

When $Q =$ in lit/day

$$= 500 \times 10^3 \times 24 \text{ lit/d}$$

$V =$ in lit

$$= 4000 \times 10^3 \text{ lit}$$

Q.15 (c)

Sludge age, or sludge residence θ_c

$$= \frac{V \cdot X_t}{Q_E \cdot X_E + Q_w \cdot X_w}$$

$$\theta_c = \frac{V \cdot X_t}{Q_w \cdot X_w} \text{ since } X_E \text{ is not given}$$

θ_c is in days

Q.16 (b)

Q.17 (b)

$$\text{SLR, } V_0 = 30 \text{ m}^3/\text{day/m}^2$$

$$= 3.472 \times 10^{-4} \text{ m/sec}$$

$$S = 2.65 \Rightarrow \rho_p = 2650 \text{ kg/m}^3$$

$$\rho = 1000 \text{ kg/m}^3$$

$$\mu = 0.001 \text{ N.S/m}^2$$

For 100% removal $V_0 = V_s$

$$V_s = \frac{g(\rho_p - \rho_w)}{18\mu}$$

$$3.472 \times 10^{-4} = \frac{9.81(2650 - 1000)d^2}{18 \times 0.001}$$

$$d = 1.96 \times 10^{-5} \text{ m}$$

$$\Rightarrow d = 0.0196 \text{ mm} = 0.02 \text{ mm}$$

Q.18 (a)

Aerobic heterotrophs:

They are organisms that cannot live without free oxygen and do not produce their own food.

Q.19 (c)

$Q_s = 2 \text{ m}^3/\text{s}$, BOD ultimate, $L_s = 90 \text{ mg}/\ell$

$$Q_R = 12 \text{ m}^3/\text{s}; L_R = 5 \text{ mg}/\ell$$

$$(BOD)_{\text{mix}} = \frac{90 \times 2 + 12 \times 5}{2 + 12} = 17.14 \text{ mg}/\ell$$

$$\text{Velocity of River flow, } V_R = \frac{Q}{A} =$$

$$\frac{12 + 2}{50} = 0.28 \text{ m/s}$$

$$\text{Time taken to travel } 10 \text{ km} = \frac{10000}{0.28}$$

$$= 35714.28 \text{ s} = 0.41 \text{ d}$$

$$L_t = L_0 \times e^{-kt} = 17.14 \times e^{-0.25 \times 0.41}$$

$$= 15.46 \text{ mg/l}$$

Q.20 (a)

Let density of sludge is ρ

$$\frac{C_1 + C_2}{\rho} = \frac{C_1}{\rho_1} + \frac{C_2}{\rho_2}$$
$$\Rightarrow \rho = \frac{100}{\frac{C_1}{\rho_1} + \frac{C_2}{\rho_2}}$$

Q.21 112.67

$$Q = 32.5 \text{ m}^3 / \text{d} / \text{m}^2$$

$$L = 32.5 \text{ m}$$

$$B = 8 \text{ m}$$

$$D = 2.25 \text{ m}$$

$$V_0 = \frac{Q}{BL}$$

$$Q = V_0 BL$$

$$Q = V_0 BL$$

$$= 32.5 \times 32.5 \times 8$$

$$= 8450 \text{ m}^3 / \text{d}$$

Weir length = 75m.

$$q = \frac{8450}{75} = 112.67 \text{ m}^3 / \text{d} / \text{m}$$

Q.22 (a)

9

AIR AND SOUND POLLUTION

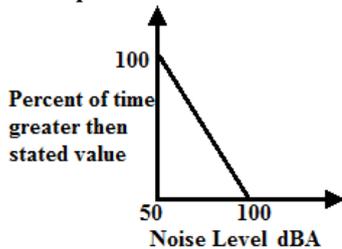
Q.1 The mean indoor airborne Chloroform (CHCL₃) concentration in a room was determined to be 0.4 μg/m³. Use the following data: T = 293K, P = 1 atmosphere, R = 82.05 × 10⁻⁶ atm.m³/mol-K, Atomic weights:

C = 12, H = 1, Cl = 35.5. This concentration expressed in parts per billion (volume basis, ppbv) is equal to

- a) 1.00 ppbv
- b) 0.20 ppbv
- c) 0.10 ppbv
- d) 0.08 ppbv

[GATE - 2006]

Q.2 The cumulative noise power distribution curve at a certain location is given below. The value of L₄₀ is equal to



- a) 90 dBA
- b) 80 dBA
- c) 70 dBA
- d) 60 dBA

[GATE - 2006]

Q.3 50g of CO₂ and 25 g of CH₄ are produced from the decomposition of municipal solid waste (MSW) with a formula weight of 120 g. What is the average per capita green house gas production in a city of 1 million people with a MSW production rate of 500 ton/day?

- a) 104 g/day
- b) 120 g/day
- c) 208 g/day
- d) 313 g/day

[GATE - 2007]

Q.4 The dispersion of pollutants in atmosphere is maximum when

- a) Environmental lapse rate is greater than adiabatic lapse rate

- b) Environmental lapse rate is less than adiabatic lapse rate
- c) Environmental lapse rate is equal to adiabatic lapse rate
- d) Maximum mixing depth is equal to zero

[GATE - 2007]

Q.5 Two electrostatic precipitators (ESPs) are in series. The fractional efficiencies of the upstream and downstream ESPs for size d_p are 80% and 65%, respectively. What is the overall efficiency of the system for the same d_p?

- a) 100%
- b) 93%
- c) 80%
- d) 65%

[GATE - 2007]

Q.6 Two biodegradable components of municipal solids waste are

- a) Plastics and wood
- b) Cardboard and glass
- c) Leather and tin cans
- d) Food wastes & garden trimmings

[GATE - 2008]

Q.7 Two primary air pollutants are

- a) Sulphur oxide and ozone
- b) Nitrogen oxide & peroxyacetyl nitrate
- c) Sulphur oxide and hydrocarbon
- d) Ozone and peroxyacetyl nitrate

[GATE - 2008]

Q.8 Particulate matter (fly ash) carried in effluent gases from the furnaces burning fossil fuels are better removed by

- a) Cotton bag house filter
- b) Electrostatic precipitator (ESP)
- c) Cyclone
- d) Wet scrubber

[GATE-2009]

Q.9 Match List-I with List-II and select the correct answer by using the codes given below the lists:

List I

- A. Coriolis effect
- B. Fumigation
- C. Ozone layer
- D. Maximum mixing depth (mixing height)

List II

- 1. Rotation of earth
- 2. Lapse rate and vertical temperature profile
- 3. Inversion
- 4. Dobson

Codes A B C D

- (a) 2 1 4 3
- (b) 2 1 3 4
- (c) 1 3 2 4
- (d) 1 3 4 2

[GATE-2009]

Q.10 The reference pressure used in the determination of sound pressure level is.

- a) $20\mu\text{Pa}$ b) 20db
- c) $10\mu\text{Pa}$ d) 10db

[GATE - 2009]

Q.11 A coastal city produces municipal solid waste (MSW) with high moisture content, High organic materials, low calorific value and low inorganic materials. The most effective and sustainable option for MSW management in that city is

- a) Composting b) Dumping
- c) Incineration d) Landfill

[GATE - 2010]

Q.12 An air parcel having 40°C temperature moves from ground level to 500 m elevation in dry air following the "adiabatic lapse rate". The resulting temperature of air parcel at 500m elevation will be

- a) 35° b) 38°
- c) 41° d) 44°

[GATE - 2010]

Q.13 According to the Noise Pollution (Regulation and control) Rules, 2000, of the Ministry of

Environment and Forests, India, the day time and night time noise level limits in ambient air for residential areas expressed in dB (A) Leq are

- a) 50 and 40 b) 55 and 45
- c) 65 and 55 d) 75 and 70

[GATE - 2010]

Q.14) Consider four common air pollutants found in urban environments, NO, SO₂, Soot and O₃. Among these which one is the secondary air pollutant?

- a) O₃ b) NO
- c) SO₂ d) Soot

[GATE - 2011]

Q.15 Total suspended particulate matter (TSP) concentration in ambient air is to be measured using a high volume sampler. The filter used for this purpose had an initial dry weight of 9.787 g. The filter was mounted in the sampler and the initial air flow rate through the filter was set at 1.5 m³/min. Sampling continued for 24 hours. The airflow after 24 hour was measured to be 1.4 m³/min. The dry weight of the filter paper after 24 hour sampling was 10.283 g assuming a linear decline in the flow rate during sampling, What is the 24 hour average TSP concentration in the ambient air?

- a) $59.2\mu\text{g}/\text{m}^3$ b) $118.6\mu\text{g}/\text{m}^3$
- c) $237.5\mu\text{g}/\text{m}^3$ d) $574.4\mu\text{g}/\text{m}^3$

[GATE - 2011]

Q.16 Elevation and temperature data for a place are tabulated below:

| Elevation, m | Temperature °C |
|--------------|----------------|
| 4 | 21.25 |
| 444 | 15.70 |

Based on the above data, lapse rate can be referred as:

- a) Super - adiabatic b) Neutral
- c) Sub-adiabatic d) Inversion

[GATE - 2013]

Q.17 The concentration of Sulfur Dioxide (SO₂) in ambient atmosphere was measured as 30 μg / m³. Under the same conditions, the above SO₂ concentration expressed in ppm is _____

Given : $\frac{P}{(RT)} = 41.6 \text{ mol / m}^3$; where

P=Pressure; T=Temperature ;
R=universal gas constant; Molecular weight of SO₂ = 64.

[GATE - 2015]

Q.18 SO₂ and CO adversely affect

- oxygen carrying capacity of blood and functioning of lungs respectively
- functioning of the respiratory system and brain respectively
- functioning of the respiratory system and oxygen carrying capacity of blood respectively
- functioning of air passages and chest respectively.

[GATE - 2015]

Q.19 It was decided to construct a fabric filter, using bags of 0.45 m diameter and 7.5 m long, for removing industrial stack gas containing particulates. The expected rate of airflow into the filter is 10m³/s. If the filtering velocity is 2.0 m/min, the minimum number of bags (rounded to nearest higher integer) required for continuous cleaning operation is

a) 27

c) 31

b) 29

d) 32

[GATE - 2016]

Q.20 An electrostatic precipitator (ESP) with 5600 m² of collector plate area is 96 percent efficient in treating 185 m³/s of flue gas from a 200 MW thermal power plant. It was found that in order to achieve 97 percent efficiency, the collector plate area should be 6100 m². In order to increase the efficiency to 99 percent, the ESP collector plate area (expressed in m²) would be _____.

[GATE - 2016]

Q.21 The atmospheric layer closest to the earth surface is

- The mesosphere
- The stratosphere
- The thermosphere
- The troposphere

[GATE - 2016]

Q.22 The sound pressure (expressed in μ Pa) of the faintest sound that a normal healthy individual can hear is

- 0.2
- 20

- 2
- 55

[GATE - 2016]

Q.23 A noise meter located at a distance of 30 m from a point source recorded 74 dB. The reading at a distance of 60 m from the point source would be _____dB.

[GATE - 2016]

ANSWER KEY:

| | | | | | | | | | | | | | |
|-----|-----|------|-----|-----|------|-----|-----|------|-----|-----|-----|-----|-----|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| (d) | (b) | (d) | (a) | (b) | (d) | (c) | (b) | (d) | (a) | (a) | (a) | (b) | (a) |
| 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | | | | | |
| (c) | (a) | 0.01 | (c) | (b) | 8011 | (d) | (c) | 67.9 | | | | | |

EXPLANATIONS

Q.1 (d)

$$\text{CHCl}_3 = 12 + 1 + 3 \times 35.5 = 119.5 \text{ gm molecular.}$$

$$\text{Concentration} = 0.4 \mu\text{g}/\text{m}^3 \text{ at } 273^0 \text{ k}$$

$$T_1 = 273^0 \text{ k} \quad T_2 = 293^0 \text{ k}$$

$$P_1 = 1 \quad P_e = 1$$

$$V_1 = 22.4 \text{ lit/mol} \quad V_2 = ?$$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

$$\frac{22.4}{273} = \frac{V_2}{293} \Rightarrow V_2 = 24.04 \text{ lit/mol}$$

$$\mu\text{g}/\text{m}^3 = \frac{\text{PPm} \times \text{gm.mole.} \times 10^3}{\text{lit/mol}}$$

$$0.4 = \frac{\text{PPm} \times 119.5 \times 10^3}{24.04}$$

$$\text{PPM} = 8.047 \times 10^{-5} \times 10^3$$

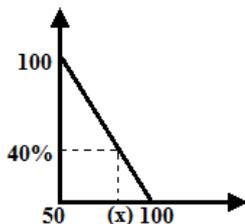
$$[\because 1 \text{ billion} = 10^9]$$

$$= 0.08$$

$$\text{Parts per billion}$$

$$= 8.074 \times 10^{-5} \times 10^3 = 0.08$$

Q.2 (b)



$$\frac{100 - 0}{100 - 50} = \frac{40 - 0}{100 - x}$$

(slope of curve is constant)

$$\therefore x = 80 \text{ dB}$$

Q.3 (d)

120g Municipal solid waste

→ 50g CO₂ + 25g CH₄

∴ 120g MSW

→ 75g(CO₂ + CH₄) Green House gas

500 tone MSW → ?

$$\therefore \frac{75 \times 500 \times 1000 \times 1000}{120}$$

∴ 500 tone MSW produce

312.5 × 10⁶ gm green house gas.

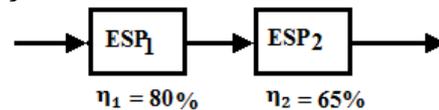
∴ Average per capita green house

$$\text{gas production} = \frac{312.5 \times 10^6}{1 \times 10^6}$$

$$= 312.5 \text{ gm/capita/day}$$

Q.4 (a)

Q.5 (b)



Let 'X' be concentration of particles in blue gas

Particles removed by ESP₁

$$= 80\% (X) = 0.8x$$

Particles remain in blue gas after ESP₁ = 0.2x

Particles removed by ESP₂

$$= 65\% (0.2x) = 0.13x$$

Particles remained in blue gas after ESP₂ = 0.07x

Overall removed

$$= \frac{X - 0.07X}{X} \times 100 = 93\%$$

Q.6 (d)

Q.7 (c)

Q.8 (b)

Q.9 (d)

List-I

- A. Coriolis effect
- B. Fumigation
- C. Ozone layer
- D. Maximum mixing depth (mixing height)

List-II

- 1. Rotation of earth
- 2. Inversion
- 3. Dobson
- 4. Lapse rate and vertical temperature profil

Q.10 (a)

Concentration SO_2 in ppm = 0.0113 ppm

Q.11 (a)

Q.18 (C)

Carbon monoxide effects the bloods carrying capacity

Q.12 (a)

Dry air cools at 9.8° per km
 $\approx 10^\circ$ km
 For $\frac{1}{2}$ km $\rightarrow 5^\circ$ fall
 Final temperature at 500 m elevation
 $= 40^\circ - 5^\circ = 35^\circ \text{C}$

Q.19 (b)

Given, $D = 0.45\text{m}$, $L = 7.5\text{m}$
 No. of fabric filter bags,

$$N = \frac{A_t}{A_b}$$

Q.13 (b)

$$\text{Total area of filter } (A_f) = \frac{10 \times 60}{2}$$

Q.14 (a)

$$= 300\text{m}^2$$

Q.15 (c)

Volume of air sampled
 $= \text{avg. rate of sampling} \times \text{duration of sampling}$

$$= \frac{1.5 + 1.4}{2} \times (24 \times 60) = 2088\text{m}^3$$

$$\frac{\text{m}^3}{\text{min}} \times \text{min}$$

TSP =

$$\text{Area of one bag } (A_b) = \pi dL$$

$$= \pi \times 0.45 \times 7.5 = 10.60\text{m}^2$$

$$N = \frac{300}{10.60} = 28.28 \approx 29$$

Q.20 (8011.8)

$$A = \frac{-Q}{we} \ln(1 - \eta_0)$$

$$\text{So, } \frac{A_1}{\ln(1 - \eta_1)} = \frac{A_2}{\ln(1 - \eta_2)}$$

$$\Rightarrow \frac{5600}{\ln(1 - 0.96)} = \frac{A}{\ln(1 - 0.99)}$$

$$\Rightarrow A = 8011.8\text{m}^2$$

$\frac{\text{final weight filter paper} - \text{Initial weight of filter paper}}{\text{Volume of air sampled}}$

$$= \frac{10.283 - 9.787}{2088} = 2.375 \times 10^{-4} \text{ gm/m}^3$$

$$= 2.375 \times 10^4 \times 10^6 = 237.547 \mu\text{g/m}^3$$

Q.16 (a)

Lapse rate

$$= \frac{dT}{dt} = \frac{21.25 - 15.70}{444 - 4} = 1.42/100$$

Lapse rate > ALR ($-1^\circ\text{C}/100\text{m}$)
 ($-1.42/100\text{m}$)

\therefore it is super adiabatic lapse rate

Q.21 (d)

Q.22 (c)

Faintest sound that a normal healthy individual can hear $20\mu\text{pa}$

Q.17 0.0133

1 m³ of air has 30 mg SO_2

10⁶ m³ of air has 30g SO_2

$$= \frac{30}{60} \text{ mol } \text{SO}_2$$

$$V = \frac{nRT}{P} = \frac{n}{P/RT} = \frac{30/64}{41.6} = \frac{\text{mol}}{\text{mol/m}^3}$$

$$= \frac{30}{64 \times 41.6} = 0.0113 \text{ m}^3$$

Q.23 (67.9)

$$L_{60} = L_{30} - 20 \log_{10} \left(\frac{60}{30} \right)$$

$$= 74 - 20 \log_{10} 2 = 67.9\text{dB}$$

ASSIGNMENT QUESTIONS

Q.1 The multiplying factor, as applied to obtain the maximum daily water demand, in relation to the average i.e. per capita daily demand, is
 a) 1.5 b) 1.8
 c) 2.0 d) 2.7

Q.2 If the average daily water consumption of a city is 24000 cum, the peak hourly demand (of the maximum day) will be
 a) 1000 cum/hr b) 1500 cum/hr
 c) 1800 cum/hr d) 2700 cum/hr

Q.3 As compared to the geometrical increase method of forecasting population, the arithmetical increase method gives
 a) lesser value
 b) higher value
 c) equal value
 d) may vary as it may depend on the population figures

Q.4 The growth of population can be conveniently represented by a curve, which is amenable to mathematical solution. The type of this curve is
 a) semilog curve
 b) straight line curve
 c) logistic curve
 d) exponential curve

Q.5 The total water consumption per capita per day, including domestic, commercial, and industrial demands, for an average Indian city, as per IS code, may be taken as
 a) 135 l/c/d b) 210 l/c/d
 c) 240 l/c/d d) 270 l/c/d

Q.6 The population figures in a growing town are as follows:

| Year | Population |
|------|------------|
| 1970 | 40,000 |
| 1980 | 46,000 |
| 1990 | 53,000 |
| 2000 | 58,000 |

The predicted population in 2010 by arithmetic regression method is

- a) 62,000 b) 63,000
 c) 64,000 d) 65,000

Q.7 The domestic use of water amounts to _____ of the total water requirements per capita per day
 a) 40% b) 50%
 c) 20% d) 30%

Q.8 Freeman's formula for estimating the fire demand (Q) in l.p.m. is given by

a) $Q=1136\left(\frac{P}{10}+10\right)$

b) $Q=2500\left(\frac{P}{5}+10\right)$

c) $Q=2715\sqrt{P}$

d) $Q=3715\sqrt{P}$

P = population in thousands

Q.9 Which one of the following methods gives the best estimate of population growth of a community with limited land area for future expansion?
 a) Arithmetical increase method
 b) Geometrical increase method
 c) Incremental increase method
 d) Logistic method

Q.10 The formula, which is most appropriate for the design of pressure pipes is
 a) Darcy Weisbach formula
 b) Mannings formula
 c) Chezy's formula
 d) Dupuit's formula

- Q.11** The internal pressure, to which a water supply pipe is subjected to, is
- full hydrostatic pressure when water in the pipe is at rest
 - pressure head and velocity head in the pipe, when flow at full velocity is taking place
 - a + water hammer pressure
 - b + water hammer pressure
- Q.12** The valve, which allows the flow only in one direction, is a
- reflux valve
 - sluice valve
 - gate valve
 - None of these
- Q.13** The valve, which is provided in the water distributing pipes at street corners and pipe junctions to control the flow in the distribution system, is
- an air valve
 - a sluice valve
 - a scour valve
 - a reflux valve
- Q.14** Scour valves are provided
- at the street corners to control the flow
 - at the dead ends to drain out the wastewater
 - at every summit of the rising main
 - at the foot of the rising main along the slope, to prevent back running of water
- Q.15** Cast iron pipes having plain ends, are joined by a joint, called
- flanged joint
 - spigot and socket joint
 - dresser coupling
 - None of these
- Q.16** Consider the following statements:
The basic difference between water pipes and sewer pipes is
- In the material used for the pipes
 - In the pressure of the liquid flow
 - In the suspended solids they carry
- Which of these statements is/are correct?
- 1 and 3
 - 1 only
 - 2 and 3
 - 1, 2 and 3
- Q.17** By using economical diameter of water mains, the benefit obtained is in terms of
- minimum pumping cost
 - use of cheapest pipe
 - minimum cost of pipe and pumping
 - none of the above benefit is attained
- Q.18** Consider the following pairs:
- Darcy Weisbach Equation.....
 $V=C\sqrt{RS}$
 - Manning's Equation $V = \frac{1}{n} R^{2/3} S^{1/2}$
 - Hazen's William Equation..... $V = kCR^{0.63}S^{0.54}$
 - Chezy's Equation.....
 $\frac{h_f}{L} = \frac{f}{d} \left(\frac{V^2}{2g} \right)$
- Which of these pairs are correct?
- 1 and 2
 - 2 and 3
 - 3 and 4
 - 1 and 4
- Q.19** The threshold odour number (TON) for a water sample of 40 ml, diluted to standard 200 ml mixture, in which odour is just barely detectable to the sense of smell, is
- 8
 - 5
 - 50
 - None of these
- Q.20** Water is considered 'hard', if its hardness is of the order of
- 50 ppm
 - 100 ppm
 - 200 ppm
 - 300 ppm
- Q.21** Electrical conductivity (EC) of water and total dissolved solids (TDS) are interrelated. The value of EC will
- decreases with increase in TDS
 - increases with increase in TDS
 - decreases initially and then increase with increase in TDS

- d) increases initially and then decrease with increase in TDS
- Q.22** Which one of the following organisms is responsible for enteric fever?
 a) ECHO
 b) Salmonella typhi
 c) Entamoeba histolytica
 d) Echinococcus
- Q.23** The maximum permissible limit For fluoride in drinking water is
 a) 0.1 mg/l b) 1.5 mg/l
 c) 5 mg/l d) 10 mg/l
- Q.24** Phenolphthalein indicator is used to determine the alkalinity above pH
 a) 8.3 b) 7.0
 c) 6.5 d) 4.5
- Q.25** If pH value of solution A is 4 and that of solution B is 5, then the hydrogen-ion concentration of solution
 a) A is ten times higher than that of B
 b) B is double than that of A
 c) A is ten times lesser than that of B
 d) A is double than that of B
- Q.26** If the hardness of a sample water, expressed in ppm of calcium carbonate is more than 300, the sample will be treated as
 a) hard water
 b) moderately hard water
 c) soft water
 d) very hard water
- Q.27** A waste water sample diluted to 100 times with aeration water had an initial dissolved oxygen (DO) of 7.0 mg/L and after 5 days of incubation at 20°C, the DO was zero. The BOD of waste water is
 a) 700 mg/L
 b) 100 mg/L
 c) can't be determined
 d) 7 mg/L
- Q.28** The treatments which are generally given to treat raw water supplies, follow the sequence
 a) screening, sedimentation, disinfection, filtration
 b) screening, sedimentation, filtration, disinfection
 c) screening, sedimentation, disinfection, aeration
 d) screening sedimentation, coagulation filtration, disinfection
- Q.29** The settling velocity of inorganic particles of less than 0.1 mm dia., varies with the dia d), in proportion to:
 a) d^3
 b) d^2
 c) d
 d) none of them, as dia does not affect the settling velocity
- Q.30** The settling velocity of inorganic particles, larger than 0.1 mm dia., varies with the dia d), in proportion to:
 a) d^3
 b) d^2
 c) d
 d) none of them, as dia does not affect the settling velocity
- Q.31** Detention time for sedimentation tank (continuous flow type), is given for a tank, passing a discharge = Q, and having length = L, width = B, and depth = H, as:
 a) $\frac{BLH}{Q}$ b) $\frac{Q}{BLH}$
 c) $\frac{Q}{BL}$ d) None of these
- Q.32** Double filtration is used
 a) to increase the filtration capacity of slow sand filters
 b) to increase the filtration capacity of rapid sand filters
 c) for isolated colonies of a few houses

- d) for none of the above
- Q.33** Which of the following chemical compounds can be used for dechlorination of water?
 a) carbon dioxide
 b) bleaching powder
 c) sulphur dioxide
 d) chloramines
- Q.34** 'Air binding' may occur in
 a) Sewers b) Artesian well
 c) Aerator d) Filters
- Q.35** Disinfection efficiency is
 a) reduced at higher pH value of water
 b) unaffected by pH value of water
 c) increased at higher pH value of water
 d) highest at pH values equal to 7
- Q.36** Available chlorine in bleaching powder solution is 0.3 mg/ml. To obtain a chlorine dose of 0.1 mg/l in a 200 ml water sample, the amount of bleaching powder solution to be added is
 a) $\frac{0.1}{200} \times 0.3ml$
 b) $\frac{0.1}{200} \times 100 \times 0.3ml$
 c) $\frac{0.1}{1000} \times 200 \times 0.3ml$
 d) $\frac{0.1}{1000} \times 200 \times \frac{1}{0.3} ml$
- Q.37** The suitable layout for a water supply distribution system, for an irregularly grown town, is
 a) dead end system
 b) grid iron system
 c) ring system
 d) radial system
- Q.38** The suitable layout for a water supply distribution system, for a city of roads of rectangular pattern, is
 c) ring system
 d) radial system
- Q.39** Which one of the following pairs is not correctly matched?
 a) Check valve : To check water flow in all directions
 b) Sluice valve : To control flow of water through pipelines
 c) Air valve : To release the accumulated air
 d) Scour valve : To remove silt in a pipeline
- Q.40** Reciprocating pumps are suitable for
 a) low discharge and high head
 b) high discharge and low head
 c) low discharge and low head
 d) high discharge and high head
- Q.41** Which one of the following valves is seldom used in water distribution systems because of high head loss characteristics?
 a) Butterfly b) Globe
 c) Plug d) Sluice
- Q.42** Sonoscope is used for which one of the following?
 a) Checking the accuracy of water meters
 b) Regulating the fire hydrants
 c) As a replacement of venturimeter for discharge measurement
 d) Detection of leakage in underground water mains
- Q.43** Consider the following statements:
 In a water supply system,
 1. drain valves are provided at elevated or higher, points to remove accumulated air.
 2. Reflux valve allow flow in one direction only.
 3. Drain valves are provided at low points to remove silt and other deposits.

Which of these statements is/are correct?

- a) 1, 2 and 3 b) 2 only
c) 2 and 3 only d) 3 only

Q.44 Consider the following statements:
The disadvantages of employing steel pipes in conveyance and distribution of water are, they

1. cannot withstand high negative pressures or vacuums that may be created in them, especially the combined effects of vacuum and external loads of backfill and traffic.
2. Are easily affected by acidic or alkaline waters and even atmospheric agencies may produce adverse effects on them.
3. Cannot be used for high pressures. (Generally not used for pressures above 7kg/cm^2)

Which of these statements is/are correct?

- a) 1, 2 and 3 b) 1 and 2 only
c) 2 and 3 only d) 1 only

Q.45 The connection of service pipe with municipal water mains supplying water to a building comprises of

1. stop cock 2. goose neck
3. ferrule 4. water meter

The correct sequence of these is

- a) 1, 2, 3, 4 b) 3, 1, 2, 4
c) 3, 2, 1, 4 d) 1, 2, 4, 3

Q.46 The ratio of maximum daily sewage flow to the average daily sewage flow for sewer mains of 0.5 to 1 m diameter, is generally taken as

- a) 1.5 b) 2.0
c) 3.0 d) None of these

Q.47 The ratio of minimum hourly flow to the average flow of sewage, is

- a) $1/3$ b) $1/2$
c) $2/3$ d) 3

Q.48 The drainage discharge of a town of 16 hectares area, consisting of 40%

hard paved ($k = 0.8$), 30% unpaved ($k = 0.20$), and remaining as wooded ($k = 0.1$), with a max. rain intensity of 5 cm/hr, would be computed by Rational formula, as equal to

- a) 0.91 cumecs b) 0.091 cumecs
c) 9.1 cumecs d) None of these

Q.49 In a circular sewer of dia D , if the depth of flow is $D/4$, the wetted perimeter will be equal to

- a) $\frac{\pi D}{4}$ b) $\frac{\pi D}{2}$
c) $\frac{\pi D}{3}$ d) None of these

Q.50 The slope of a 1.0 m diameter concrete sewer laid at a slope of 1 in 1000 develops a velocity of 1 m/s, when flowing full. When it is flowing half-full, the velocity of flow through the sewer will be

- a) 0.5 m/s b) 1.0 m/s
c) 2 m/s d) 2.0 m/s

Q.51 The diameter of a circular sewer has following ratio to the side of a hydraulically equivalent square section of sewer

- a) 0.95 b) 1.0
c) 1.095 d) 1.25

Q.52 The maximum velocity in a sewer of diameter d will be obtained when depth of flow is equal to

- a) d b) $0.5 d$
c) $0.808 d$ d) $0.95 d$

Q.53 What is the maximum distance between successive manholes in sewers of diameter more than 1.5 m?

- a) 75 m b) 300 m
c) 500 m d) 150 m

Q.54 The drop manholes are provided in a sewerage system when there is

- a) change in alignment of sewer line
b) change in size of sewers

- c) change in the elevation of ground level
d) change from gravity system to pressure system
- Q.55** Gases, which are generally evolved during aerobic decomposition of sewage, are:
a) $\text{CO}_2 + \text{NH}_3 + \text{H}_2\text{S}$
b) $\text{CO}_2 + \text{NH}_3 + \text{H}_2\text{S} + \text{CH}_4$
c) $\text{CO}_2 + \text{NH}_3 + \text{SO}_2$
d) $\text{CO}_2 + \text{NH}_3 + \text{SO}_2 + \text{CH}_4$
- Q.56** pH = 3, when compared to pH = 5, will be more acidic by
a) 2 times b) 20 times
c) 100 times d) none of them
- Q.57** The average BOD_5 of domestic sewage is
a) 80 kg/day/person
b) 8 kg/day/person
c) 0.8 kg/day/person
d) 0.08 kg/day/person
- Q.58** The relative stability of a sewage sample, whose D.O. equals the total oxygen required to satisfy its BOD, is
a) zero b) 1%
c) 100% d) infinity
- Q.59** Complete thorough treatment should generally be given to sewage, before its disposal in a stream, if the dilution factor available is
a) less than 350 b) less than 250
c) less than 150 d) None of these
- Q.60** One litre of sewage, when allowed to settle for 30 minutes gives a sludge volume of 27 cm^3 . If the dry weight of this sludge is 3.0 grams, then its sludge volume index will be
a) 9 b) 24
c) 30 d) 81
- Q.61** A drain carrying sewage of BOD = 200 mg/L and flow rate of $50 \text{ m}^3/\text{s}$ joins a river whose upstream BOD is 8 mg/L and flow rate is $500 \text{ m}^3/\text{s}$. Assume immediate and complete mixing of drain with the river. What is the estimated downstream BOD of the river flow?
a) 20.4 mg/L b) 25.4 mg/L
c) 104.4 mg/L d) 70.4 mg/L
- Q.62** The five-day BOD of a waste water sample is 150 mg/l at 20°C . The reaction constant 'k' (to the base 'e') is 0.2 per day. The ultimate first stage BOD is ($'e' = 2.72$)
a) 225.5 mg/l b) 237.2 mg/l
c) 240 mg/l d) 245.5 mg/l
- Q.63** The 'sag' in the dissolved oxygen curve results because
a) it is a function of the rate of addition of oxygen to the stream
b) it is a function of the rate of depletion of oxygen from the stream
c) it is a function of both addition and depletion of oxygen from the stream
d) the rate of addition is linear but the rate of depletion is non-linear
- Q.64** Which of the following match is not correct?
a) Lagooning – sludge disposal
b) Elutriation – Washing of digested sludge
c) Filtration – Removal of suspended solids and organic matter
d) None of these
- Q.65** Sludge digestion is a process of sewage
a) Treatment b) Screening
c) Catching d) All of these
- Q.66** The total volume of a primary settling tank is 2500 m^3 and the waste water flow is 25×10^6 litres per day. The detention time in settling tank is

- a) $\frac{10}{24}$ h b) $\frac{24}{10}$ h
 c) 24 h d) $\frac{1}{24}$ h

Q.67 Acceptable lower limit of bacteria Removal through activated sludge process is
 a) 60% b) 70%
 c) 80% d) 90%

Q.68 If the efficiencies of BOD removal of first-stage and second-stage trickling filters are each 65.0%, then what is the overall BOD removal efficiency of these filters?
 a) 65% b) 77.25%
 c) 87.75% d) 92.6%

Q.69 A septic tank of 7 m³ in volume serves for 5 people. If the rate of accumulation of sludge is 70 litres per capita per year and sludge is removed when it occupies 50% of its volume, what is the cleaning interval of septic tank?
 a) 3 years b) 5 years
 c) 7.5 years d) 10 years

Q.70 Where does sloughing occur?
 a) Grit chamber
 b) Biological treatment unit
 c) Trickling filter
 d) Septic tank

Q.71 A township is to treat 5,00,000 litres of sewage per day which has a 5 day BOD of 150 ppm. An oxidation pond is used for the purpose. The effluent can have a BOD of 15 ppm. The loading is to be 40 kg of 5 day BOD per hectare per day. The required area of the pond is
 a) 1.6875 ha b) 1.875 ha
 c) 1.975 ha d) 2 ha

Q.72 Symbiosis, the beneficial association between algae and bacteria is used for treatment of waste water in the following unit?
 a) Activated Sludge

- b) Rotating Biological Disc
 c) Anaerobic Digester
 d) Oxidation Pond

Q.73 An intercepting trap is provided at the junction of
 a) a house sewer and a municipal sewer
 b) an unfoul house drain and a foul house drain
 c) any two house drains
 d) None of these

Q.74 A gully trap is provided at the junction of
 a) a house sewer and a municipal sewer
 b) an unfoul house drain and a foul house drain
 c) any two house drains
 d) None of these

Q.75 The pipe in house plumbing, which carries the discharge from sanitary fittings like bath rooms, etc., is called
 a) waste pipe b) soil pipe
 c) anti-siphonage d) vent pipe

Q.76 Two pipe system of providing building drainage consists of
 a) one soil pipe + one waste pipe + one vent pipe + one sullage pipe
 b) one soil pipe + one waste pipe + two vent pipes
 c) two soil pipes + two waste pipes
 d) two soil pipes only

Q.77 Match List-I and List-II and select the correct answer using the codes given below the lists:

| List-I | List-II |
|-----------------|-----------------------|
| A. Soil pipe | 1. Ventilating pipe |
| B. Intercepting | 2. Wash basin trap |
| C. P-trap | 3. Water closet waste |
| D. Cowl | 4. House drainage |

Codes:

- | | A | B | C | D |
|----|---|---|---|---|
| a) | 3 | 4 | 1 | 2 |
| b) | 3 | 4 | 2 | 1 |
| c) | 4 | 3 | 2 | 1 |
| d) | 4 | 3 | 1 | 2 |

Q.78 Which one of the following would help prevent the escape of foul sewer gases from a water closet?

- a) Air gap b) Vent pipe
c) Gully trap d) None of these

Q.79 Soil pipe in plumbing services means a pipe

- a) made of clay
b) carrying soiled materials
c) carrying waste from water closets
d) carrying industrial waste water

Q.80 Match List-I (Type of waste) and List-II (Description) and select the correct answer using the codes given below the lists:

List-I

- A. Refuse
B. Sullage
C. Sewage
D. Rubbish

List-II

1. Wastes of comubustible nature
2. Waste water with higher decomposable fraction
3. All kinds of wastes
4. Waste water with low biodegradable fraction

Codes:

- | | A | B | C | D |
|----|----------|----------|----------|----------|
| a) | 2 | 1 | 3 | 4 |
| b) | 3 | 4 | 2 | 1 |
| c) | 2 | 4 | 3 | 1 |
| d) | 3 | 1 | 2 | 4 |

Q.81 Match List-I (Type of trap) with List-II (location) and select the correct answer using the codes given below the lists:

| List-I | List-II |
|----------------------|---|
| A. Intercepting trap | 1. Junction of sullage and storm water drains |
| B. Gully trap | 2. At the head of each house drain |
| C. Nahni trap | 3. Junction of house drain and street sewer |
| D. P-trap | Water closet |

Codes:

- A B C D

- a) 3 1 4 2
b) 4 2 3 1
c) 3 2 4 1
d) 4 1 3 2

Q.82 The method of refuse disposal, involving burial in trenches, is called

- a) incineration b) pulverisation
c) composting d) None of these

Q.83 Which one of the following solid waste disposal methods is ecologically most acceptable?

- a) Sanitary landfill b) Incineration
c) Composting d) Pyrolysis

Q.84 Sewage sickness occurs when

- a) sewage contains pathogenic organisms
b) sewage enters the water supply system
c) sewers get clogged due to accumulation of solids
d) voids of soil clogged due to continuous application of sewage on a piece of land

Q.85 Which of the following materials are used as landfill sealants for the control of gas and leachate movements?

1. Lime
2. Sand
3. Bentonite
4. Fly ash
5. Butyl rubber

Select the correct answer using the codes given below:

- a) 1, 2 and 3 b) 4 and 5
c) 3 and 5 d) 1, 2 and 4

Q.86 Which one of the following statements explains the term pyrolysis?

- a) Solid waste is heated in closed containers in oxygen-free atmosphere
b) Solid waste is incinerated in presence of oxygen

- c) Wastewater is treated with oxygen
- d) Dissolved solids from water are removed by glass distillation

Q.87 Allowable disposable rate of application of sludge on land is determined by

- a) carbon content of sludge
- b) nitrogen content of sludge
- c) phosphorus content of sludge
- d) potassium content of sludge

Q.88 What are the gases produced by landfills primarily comprised of?

- a) Carbon monoxide and hydrogen sulphide
- b) Methane and carbon dioxide
- c) Sulphur dioxide and nitrogen dioxide
- d) Ethane and oxygen

Q.89 A primary sludge having volume of 14 m³ and moisture content of 94% was dewatered to have a solid content of 16%. What is its final volume?

- a) 2.38m³
- b) 3.50 m³
- c) 5.25 m³
- d) 7.00 m³

Q.90 The leachate is an effluent from which of the following?

- a) Septic tanks
- b) Sanitary lands fills
- c) Compost plants
- d) Aerated lagoons

Q.91 Pollution by depletion of ozone layer, in the environment, is caused due to the reaction of ozone with

- a) carbon monoxide
- b) chlorine
- c) sulphur dioxide
- d) nitrous oxide

Q.92 Match List-I with List-II and select the correct answer using the codes given below the lists:

| List-I | List-II |
|--------------------|-------------------------------------|
| A. CO | 1. Greenhouse effect |
| B. CO ₂ | 2. Acid rains |
| C. SO ₂ | 3. Acute toxicity |
| D. NO _x | 4. Ozone liberation at ground level |

Codes:

| | A | B | C | D |
|----|---|---|---|---|
| a) | 3 | 2 | 4 | 1 |
| b) | 2 | 3 | 4 | 1 |
| c) | 1 | 2 | 4 | 3 |
| d) | 4 | 1 | 2 | 3 |

Q.93 Two sources generate noise levels of 90 dB and 94 dB respectively. The cumulative effect of these two noise levels on the human ear is

- a) 184 dB
- b) 95.5 dB
- c) 94 dB
- d) 92 dB

Q.94 Which one of the following plume behaviours occurs when atmospheric inversion begins from the ground level and continues?

- a) Looping
- b) Fumigation
- c) Coning
- d) Fanning

Q.95 Which of the following pairs are Correctly matched?

1. Reverberation time : Time required to reduce noise by 60 dB
2. NIPTS: Responsible for permanent hearing loss
3. Sound foci: Formed when sound waves are reflected from convex surface
4. TTS: Responsible for temporary hearing loss

Select the correct answer using the codes given below:

- a) 2, 3 and 4
- b) 1, 3 and 4
- c) 1, 2 and 4
- d) 1, 2 and 3

Q.96 The following is a well know formula for estimating the plume

$$\text{rise: } \Delta h = \frac{V_{sd}}{u} \left(1.5 + 0.0096 \frac{Q_h}{V_{sd}} \right)$$

where the letters have their usual meaning. The estimated plume rise (by the above formula) with a stack gas having heat emission rate 2000 kJ/s, the wind speed 4 m/s, stack gas speed 8 m/s inside a stack diameter of 1 m at the top is

- a) 7.8 m b) 8.7 m
 c) 3.15 m d) $\frac{8000}{\pi}(1.5+0.0024\pi)$

Q.97 Which one of the following units is employed for the removal of particulate matter above 50 μ in size?
 a) Gravity settling chamber
 b) Cyclone
 c) Fabric filter
 d) Electrostatic precipitator

Q.98 Which is the major pollutant present in photochemical smog?
 a) PAN b) SO₂
 c) HC d) NO₂

Q.99 Electrostatic precipitator is a device to control
 a) SO₂ emission
 b) particulate emission
 c) both SO₂ and particulate emission
 d) precipitation of Al(OH)₃ in water coagulation

Q.100 In urban air pollution, the most poisonous gas is supposed to be carbon monoxide. It is hazardous because it
 a) affects our sense of smell
 b) is carcinogenic in nature
 c) combines with haemoglobin
 d) causes blindness

ANSWER KEY:

| | | | | | | | | | | | | | |
|-----------|------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| (b) | (d) | (a) | (c) | (d) | (c) | (b) | (a) | (d) | (a) | (c) | (a) | (a) | (b) |
| 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 |
| (c) | (c) | (c) | (c) | (b) | (c) | (b) | (b) | (b) | (a) | (a) | (d) | (a) | (b) |
| 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 |
| (b) | (c) | (a) | (a) | (c) | (d) | (a) | (d) | (a) | (b) | (a) | (a) | (c) | (d) |
| 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 52 | 53 | 54 | 55 | 56 |
| (c) | (b) | (c) | (b) | (a) | (a) | (c) | (b) | (c) | (c) | (b) | (c) | (c) | (c) |
| 57 | 58 | 59 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 | 70 |
| (d) | (c) | (c) | (a) | (b) | (b) | (c) | (d) | (a) | (b) | (d) | (c) | (d) | (c) |
| 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | 80 | 81 | 82 | 83 | 84 |
| (a) | (d) | (a) | (b) | (a) | (b) | (b) | (d) | (c) | (b) | (b) | (c) | (c) | (d) |
| 85 | 86 | 87 | 88 | 89 | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 98 |
| (d) | (a) | (b) | (b) | (c) | (b) | (b) | (c) | (d) | (d) | (c) | (a) | (a) | (c) |
| 99 | 100 | | | | | | | | | | | | |
| (b) | (c) | | | | | | | | | | | | |

EXPLANATIONS

Q.1 (b)

Maximum daily demand = $1.8 \times$
Average daily demand
Maximum hourly demand = $1.5 \times$
Maximum daily demand

Q.2 (d)

Maximum hourly consumption of the maximum day i.e. peak demand

$$= 1.5 \times \left(\frac{1.8q}{24} \right)$$

$$= 2.7 \times \frac{24000}{24} = 2700 \text{ cum/hr}$$

Q.3 (a)

In geometric increase method compounding is done every decade unlike in arithmetic increase method. Thus geometrical increase method gives higher value than the arithmetic increase method.

Q.4 (c)

Equation of logistic curve is given by

$$\ln \left[\frac{P_s - P}{P_s - P_0} \right] = -kPt$$

where, P_0 = the population at the start pt. of the curve A

P_s = Saturation population

P = Population at any time t from the origin A

K = Constant

Q.5 (d)

Break up of per capita demand (q) for an average

Indian city

| Use | Demand in l/h/d |
|---|-----------------|
| Domestic use | 200 |
| Industrial use | 50 |
| Commercial use | 20 |
| Civil or public use | 10 |
| Wastes & thefts etc | 55 |
| Total = 335 = per capita demand (q) | |

Q.6 (c)

| Year | Population | Decadal increase |
|------|------------|------------------|
| 1970 | 40,000 | |
| 1980 | 46,000 | 6000 |
| 1990 | 53,000 | 7000 |
| 2000 | 58,000 | 5000 |

$$\therefore \text{Design growth rate,} \\ = \frac{6000 + 7000 + 5000}{3}$$

= 6000 per decade

In 2010 population will be

$$P = 58000 + 6000 = 64000$$

Q.7 (b)

Total domestic water consumption usually amounts to 50 – 60% of the total water consumption.

Q.8 (a)

Freeman's formula

$$\Rightarrow Q = 1136 \left(\frac{P}{10} + 10 \right)$$

Kuichling formula

$$\Rightarrow Q = 3182\sqrt{P}$$

P = Population in thousands

Q.9 (d)

Since the area is limited and there is estimation, therefore logistic curve method will be the best.

Q.10 (a)

Darcy-Weisbach formula is used to compute head loss in certain section of a pipe length.

$$H_f = \frac{fv^2}{2gd}$$

Q.11 (c)

The internal pressure within a pipe is caused by the water head to which the pipe can be subjected and

the additional transient pressures. The maximum internal pressure under worst circumstances is sum of full static pressure and the water hammer pressure

Q.12 (a)

Check valves or Reflux valves: Check valves are sometimes called non-return valves because they prevent water to flow back in the opposite direction. They may be installed on the delivery side of the pumping set, so as to prevent the back flow of stored or pumped water, when the pump is stopped.

Q.13 (a)

Sluice valves are used to regulate the flow of water through the pipes. They are usually placed at the summits.

Q.14 (b)

In order to remove the entire water from within a pipe (after closing the supply), small gated off-takes are provided at low points. These valves are known as blow off valves or drain valves or scour valves. These valves, are necessary at low level points for completely emptying the pipe for inspection, repairs, etc.

Q.15 (c)

This type of a joint is used when it is required to join the plain ends of cast iron pipes. The joints are strong and rigid. They can withstand vibrations and are, therefore, useful for pipes to be carried over bridges or below bridges in hangers.

Q.16 (c)

Cast iron pipes can be used for both water pipes and sewer pipes. However the basic difference is pressure flow in water pipe and suspended solids carried in sewage.

Q.17 (c)

If diameter > Economical dia

- Less cost of Pumping
- High cost of pipe material

If diameter < economical dia

- Less cost of pipe material
- High cost of pumping

Q.18 (b)

Darcy Weishbach Equation,

$$\frac{h_f}{L} = \frac{f}{d} \left(\frac{V^2}{2g} \right)$$

Chezy's equation, $V = C\sqrt{RS}$

Q.19 (b)

Threshold odour number represents the dilution ratio at which the odour is hardly detectable

$$\text{TON} = \frac{200}{40} = 5$$

Q.20 (c)

Water with hardness upto 75 ppm are considered soft while those with 200 ppm and above are considered hard. In between the waters are considered as moderately hard.

Q.2 (b)

An approximate analysis for TDS is often made by determining the electrical conductivity of the water. The ability of water to conduct electricity is called specific conductance and it is a function of its ionic strength. Unfortunately, specific conductance and concentration of TDS are not related on a one to one basis. Only ionized substances contribute to specific conductance. Organic molecules and compounds that dissolve without ionizing are not measured. Additionally, the magnitude of specific conductance is influenced by the valence of the ions in the solution, their mobility and their relative numbers. The temperature

also has an important effect with specific conductance increasing as the water temperature increases. The ions usually accounting for majority of TDS in natural waters are Na, Ca, Mg, HCO_3^- , SO_4^{2-} , Cl^- , etc. Hence their presence increases the electrical conductivity of water.

Q.22 (b)

Salmonella typhi and Salmonella paratyphi(bacteria) cause enteric fever.

Enteric Cytopathogenic Human Orphan ECHO(virus) cause aseptic meningitis, epidemic exanthema, infantile diarrhoea. Entamoeba histolytica(protozoa) cause dimeriasis(amebic dysentery, amebic enteritis, amebic colitis). Echinococcus(helminth) cause echinococcosis(hydatidosis, granulosis, dog tapeworm).

Q.23 (b)

A fluoride concentration of less than 0.8-1.0 ppm may be harmful and may cause dental caries(tooth decay) due to the formation of excessive cavities in the teeth of young children during calcinations of their permanent teeth. Higher fluoride concentrations, greater than 1.5 ppm or so, may again be harmful, causing spotting and discolouration of teeth, (a disease called fluorosis), which with continued excessive consumption of fluorides, may even cause deformation of bones.

Q.24 (a)

Phenolphthalein turns water into pink if pH is more than 8.3. At pH = 8.3, it changes the water from pink to colourless.

Q.25 (c)

$\text{pH} = -\log_{10}[\text{H}^+]$
 $\Rightarrow [\text{H}^+]_A = 10^{-4}$ and $[\text{H}^+]_B = 10^{-5}$

$$\therefore \frac{[\text{H}^+]_A}{[\text{H}^+]_B} = \frac{10^{-4}}{10^{-5}} = 10$$

Q.26 (d)

Degree of Hardness Range

Soft < 50 mg/l as CaCO_3

Moderately hard 50-150 mg/l as CaCO_3

Hard 150 - 300 mg/l as CaCO_3

Very Hard > 300 mg/l as CaCO_3

Q.27 (a)

$\text{BOD}_5 = \text{Loss of oxygen in mg/l} \times \text{Dilution ratio}$

$$\text{BOD}_5 = (7 - 0) \times 100 = 700 \text{ mg/l}$$

Q.28 (b)

Most of the big and visible objects, such as trees, branches, sticks, vegetations, fish, animal life, etc., present in raw waters of surface sources can be removed by screening. The coarser suspended materials can then be removed by letting the water settle in sedimentation basins. This process is called plain sedimentation. The finer particles in suspension, which may avoid settling in sedimentation basins even after using chemical coagulation, may then be removed by filtering the water through filters. This process is called filtration. The filtered water which may still contain pathogenic bacteria, is then made bacteria-proof by adding certain chemicals such as chlorine, ozone etc. This process is called disinfection.

Q.29 (b)

Settling velocity for particle size less than 0.1 mm

$$V_s = 418(S_s - 1)d^2 \left(\frac{3T + 70}{100} \right)$$

V_s in mm/s

d in mm

T temperature of water in $^\circ\text{C}$

Q.30 (c)

For d between 0.1 mm to 1 mm

$$V_s = 418(S_s - 1)d^2 \left(\frac{3T + 70}{100} \right)$$

For $d > 1$ mm

$$V_s = 1.8\sqrt{gd(S_s - 1)}$$

Q.31 (a)

The detention period $x(t)$ of a settling tank may be defined as the 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. In other words, it is the average time for which the water is detained in the tank. Hence, it is the ratio of the volume of the basin to the rate of flow (or discharge) through the basin.

\therefore Detention time t for a Rectangular tank

$$= \frac{\text{Volume of the tank}}{\text{Rate of flow}} = \frac{BLH}{Q}$$

Q.32 (a)

The rate of filtration of slow sand filters can be considerably increased (almost doubled) by using a preliminary filter (a rapid gravity filter of a higher filtration rate) which is called the roughening filter. The raw water (generally without coagulants) is therefore, first of all, passed through the roughening filter which partly removes impurities. The effluents are then passed through the ordinary slow sand filter, so as to get a good quality supply and also at a higher rate. The water is thus filtered twice.

Q.33 (c)

The common dechlorinating agents are: Sulphur dioxide gas ($\text{SO}_2\uparrow$), Activated carbon, Sodium

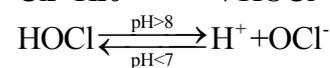
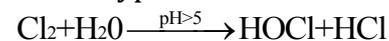
thiosulphate ($\text{Na}_2\text{S}_2\text{O}_3$), Sodium metabisulphate ($\text{Na}_2\text{S}_2\text{O}_5$), Sodium sulphite (Na_2SO_3), Sodium bisulphite (NaHSO_3), and Ammonia as NH_4OH .

Q.34 (d)

The filtration process causes blocking of filter media due to impurities arrested in them. The downward flow of water is resisted by sand grains and impurities arrested in them. A stage may reach when the frictional resistance exceeds the static head of water above the sand bed most of this resistance is caused by the top 10 to 15 cm sand layer. The bottom sand acts like a vacuum and the water is sucked through the filter media without cleaning. The dissolved air and gases from water are released and they stick to sand grains. This phenomena is called air binding and seriously affects the efficiency of filter.

Q.35 (a)

When chlorine is added to water it forms hypochlorous acid



The hypochlorous acid is most destructive and more effective than hypochlorite ions (OCl^-). Thus at high pH HOCl dissociates into OCl^- ions and disinfection efficiency is reduced.

Q.36 (d)

The chlorine requirement for 200

$$\text{ml water} = \frac{0.1 \times 200}{1000} \text{ mg}$$

Amount of bleaching powder solution needed =

$$\frac{\text{Chlorine Requirement}}{\text{Available Chlorine Concentration}}$$

$$= \frac{0.1 \times 200}{1000 \times 0.3}$$

Q.37 (a)

In the dead end system, which is also sometimes called Tree system, there is one main supply pipe, from which originates (generally at right angles) a number of submain pipes. Each submain, then divides into several branch pipes, called laterals. From the laterals, service connections are given to the consumers. This type of layout may have to be adopted for older towns which have developed in a haphazard manner, without properly planned roads.

Q.38 (b)

Grid-iron system: In this system, which is also known as Interlaced system or Reticulation system, the mains, sub-mains and branches are all inter-connected with each other in a well planned city or a town, the roads are generally developed in a grid-iron pattern, and the pipe lines in such places can follow them easily.

Q.39 (a)

Check valve does not allow flow in reverse direction.

Q.40 (a)

Reciprocating pump gives constant discharge under variable heads. It is used for low discharge under variable high heads.

Q.41 (c)

Q.42 (d)

Q.43 (c)

Drain valves are provided to remove the entire water from within a pipe (after closing the water supply). These are small gated off-takes

which are provided at low points. These are also known as blow off valves or scour valves.

Q.44 (b)

Q.45 (c)

Ferrule: A ferrule is a right angled sleeve made of brass or gun metal, and is joined to a hole drilled in the water main.

Goose neck: Goose neck is a small sized curved pipe made of a flexible material (usually lead) forming a flexible connection between the water main and the service pipe.

Service pipe: Service pipe is a galvanised iron pipe of size less than 50 mm dia. The service pipe which supplies water to the building through the municipal main is thus connected to the main through the goose neck and ferrule.

Stop cock: The stop cock is provided before the water enters the water meter in the house.

Q.46 (b)

Maximum daily flow = 2 times the average daily flow

Maximum hourly flow = 1.5 times the maximum daily flow
= 3 times the average daily flow

Q.47 (a)

Minimum daily flow = $\frac{2}{3} \times \text{Average daily}$

Minimum hourly flow = $\frac{1}{2} \times \text{Minimum Daily flow}$

= $\frac{1}{3} \times \text{Average daily}$

Q.48 (a)

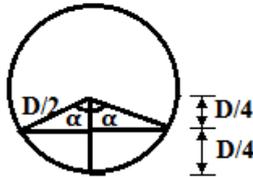
$$K_{avg} = \frac{(0.4 \times 0.8 + 0.3 \times 0.2 + 0.3 \times 0.1)}{(0.4 + 0.3 + 0.3)}$$

= 0.41

$$Q = \frac{1}{36} KIA$$

$$= \frac{1}{36} \times 0.41 \times 5 \times 16 = 0.91 \text{ cumecs}$$

Q.49 (c)



$$\cos \alpha = \frac{D/2}{D/2} = \frac{1}{2}$$

$$\alpha = 60^\circ$$

Proportionate perimeter:

$$\frac{p}{P} = \frac{2\alpha}{360} = \frac{120}{360} = \frac{1}{3}$$

$$p = \frac{\pi D}{3}$$

Q.50 (b)

$$\text{For } \frac{d}{D} = 0.5; \quad \frac{v}{V} = 1.0$$

Where d is depth of flow v is flow velocity at depth d

D is diameter of sewer

V is flow velocity at full flow

$$\therefore v = 1.0 \text{ m/s}$$

Q.51 (c)

Hydraulically equivalent square section is the one which gives the same discharge when running full at the same gradient.

$$\text{Circular sewer: } Q_c = \frac{1}{n} A_c R_c^{2/3} S^{1/2}$$

$$\text{Square sewer: } Q_s = \frac{1}{n} A_s R_s^{2/3} S^{1/2}$$

For hydraulic equivalence

$$\Rightarrow \frac{\pi D^2}{4} \times \left(\frac{\pi D^2}{4 \times \pi D} \right)^{2/3} = B^2 \times \left(\frac{B^2}{4B} \right)^{2/3}$$

$$\Rightarrow \frac{\pi D^2}{4} \times (D)^{2/3} = B^2 (B)^{2/3}$$

$$\Rightarrow \left(\frac{D}{B} \right)^{8/3} = \frac{4}{\pi}$$

$$\Rightarrow \frac{D}{B} = 1.095$$

Q.52 (c)

The maximum velocity is obtained not when the sewer is running full but when the depth of flow is 0.81 times the full depth, and is about 12.5% greater than that when running full. Similarly, the maximum discharge is obtained not when the sewer is running full, but when the depth is about 0.95 times the full depth, and is about 7% greater than that when running full.

Q.53 (b)

| Size of the Sewer | Recommended Spacing of Manholes on straight reaches of sewer lines as per IS:1742-19609 |
|-------------------|---|
| Dia upto 0.3 m | 45 m |
| Dia upto 0.6 m | 75 m |
| Dia upto 0.9 m | 90 m |
| Dia upto 1.2 m | 120 m |
| Dia upto 1.5 m | 250 m |
| Dia > 1.5 m | 300 m |

Q.54 (c)

When a branch sewer enters a manhole by more than 0.5 to 0.6 m above the main sewer, the sewage is generally not allowed to fall directly into the manhole, but is brought into it through a down pipe taken from the branch sewer to the bottom of the manhole. The manhole in which a vertical pipe is used, is called drop manhole, whereas, the one using an inclined pipe is called a ramp.

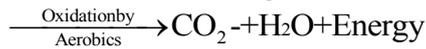
Q.55 (c)

i) Nitrogenous organic matter

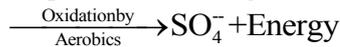
$$\xrightarrow[\text{Aerobics}]{\text{Oxidation by}} \text{NO}_3^- + \text{NH}_3 + \text{Energy}$$

Sometimes

ii) Carbonaceous organic matter



iii) Sulphurous organic matter



Q.56 (c)

$$\text{pH} = -\log \text{H}^+$$

$$\Rightarrow \text{pH} = 3$$

$$\Rightarrow \text{H}^+ = 10^{-3}$$

$$\Rightarrow \text{pH} = 3$$

$$\Rightarrow \text{H}^+ = 10^{-5}$$

$$\frac{\text{pH}(3)}{\text{pH}(5)} = \frac{10^{-3}}{10^{-5}} = 10^2 \text{ times more acidic}$$

Q.57 (d)

The average standard BOD₅ of domestic sewage is used to assess the strength of industrial sewage.

[Standard BOD (5 days) of industrial sewage] =

[Standard BOD (5 days) of domestic sewage per person per day] × [Population equivalent]

Q.58 (c)

The term relative stability of a sewage effluent may be defined as the ratio of oxygen available in the effluent (as D.O., nitrite or nitrate) to the total oxygen required to satisfy its first stage B.O.D. demand. It is expressed as percentage of the total oxygen required and can be expressed by the equation

Relative stability:

$$S = 100[1 - (0.794)^{t^{20}}] \text{ or}$$

$$S = 100[1 - (0.630)^{t^{(37)}}]$$

Q.59 (c)

Standards of Dilution based on Royal Commission Report

| Dilution Factor | Standards of purification required |
|-----------------|---|
| > 500 | No treatment is required. Raw sewage can be directly discharged into the volume of dilution water |
| Between 300 to | Primary treatment such as plain sedimentation should be given to |

| | |
|--------------------|--|
| 500 | sewage, and the effluents should not contain suspended solids more than 150 ppm |
| Between 150 to 300 | Treatments such as sedimentation, screening and essentially chemical precipitation are required. The sewage effluent should not contain suspended solids more than 60 ppm |
| < 150 | Complete through treatment should be given to sewage. The sewage effluent should not contain suspended solids more than 30 ppm., and its 5 days B.O.D. at 18.3° should not exceed 20 ppm |

Q.60 (a)

Sludge volume index is the volume occupied in mL by one gm of solids in the mixed liquor after settling for 30 minutes. It indicates the physical state of sludge produced in a biological aeration system. It is used to decide the rate of recycle of sludge(Q) required to maintain the desired Mixed Liquor Suspended Solids (MLSS) and Food to Mass (F/M) ratio in the aeration tank to achieve the desired degree of purification. So by reducing recycling ratio SVI can be controlled. The settled sludge volume $V_{ob} = 27 \text{ cm}^3/\text{lit} = 27 \text{ mL/lit}$

The concentration of suspended solids in mixed liquor, $X_{ob} = 3 \text{ g/lit}$

$$\therefore \text{SVI} = \frac{V_{ob}}{X_{ob}} = \frac{27}{3} = 9 \text{ m/gm}$$

Q.61 (b)

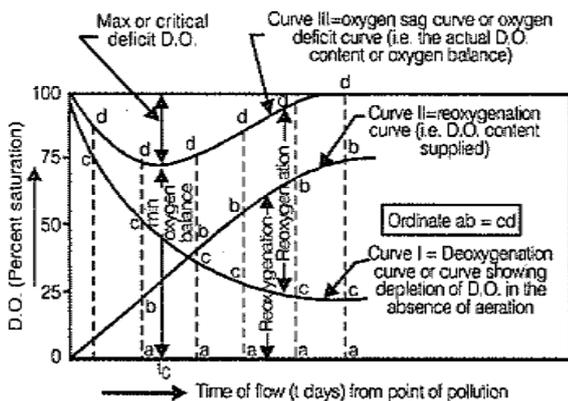
$$\begin{aligned} \text{BOD}_{\text{mix}} &= \frac{Q_S \text{BOD}_S + Q_R \text{BOD}_R}{Q_S + Q_R} \\ &= \frac{50 \times 200 + 500 \times 8}{50 + 500} \\ &= 25.45 \text{ mg/L} \end{aligned}$$

Q.62 (b)

$$\begin{aligned} \text{BOD}_5 &= \text{BOD}_u(1 - e^{-kt}) \\ \text{BOD}_u &= \frac{150}{(1 - e^{-5 \times 0.2})} = \frac{150 \times e}{e - 1} \\ &= \frac{150 \times 2.72}{1.72} = 237.2 \text{ mg/l} \end{aligned}$$

Q.63 (c)

In a running polluted stream exposed to the atmosphere, the de-oxygenation as well as the re-oxygenation go hand in hand. If de-oxygenation is more rapid than the re-oxygenation, an oxygen deficit results. The amount of resultant oxygen deficit can be obtained by algebraically adding the de-oxygenation and re-oxygenation curves. The resultant curve so obtained is called the oxygen sag curve or the oxygen deficit curve.



Q.64 (d)

Elutriation is the process of washing the sludge water to remove organic and fatty acids from it.

Q.65 (a)

Sludge digestion is a process of stabilizing the sludge by decomposing the organic matter under controlled anaerobic conditions.

Q.66 (b)

$$\begin{aligned} \text{Detention time, } t &= \frac{V}{Q} \\ &= \frac{2500}{25 \times 10^6 \times 10^{-3}} \\ &= 0.1 \text{ day} = \frac{24}{10} \text{ hr} \end{aligned}$$

Q.67 (d)

Bacteria and organisms are removed by mechanical means during waste water treatment.

| Process removal | Percent |
|------------------------|-------------|
| Coarse screens | 0 – 5 |
| Fine screens | 10 – 20 |
| Grit chambers | 10 – 25 |
| Plain sedimentation | 25 – 75 |
| Chemical precipitation | 40 – 8 |
| Trickling filters | 90 – 95 |
| Activated sludge | 90 – 98 |
| Chlorination | 98 – 99.999 |

Q.68 (c)

$$\begin{aligned} \text{Overall BOD removal efficiency} &= 65 + (100 - 65) \times \frac{65}{100} \\ &= 65 + 22.75 = 87.75\% \end{aligned}$$

Q.69 (d)

The volume of sludge at the time of cleaning = $0.5 \times 7 = 3.5 \text{ m}^3$
= 3500 litres
Rate of accumulation of sludge = $5 \times 70 = 350 \text{ litre/year}$

$$\text{Cleaning interval} = \frac{3500}{350} = 10 \text{ year}$$

Q.70 (c)

With continuous growth of microbes on the surface of filtering media, the inner layer organisms die due to deficiency of food and loose contact with the surface of media. The shearing stress of flowing sewage remove these layers of organisms. This is called sloughing in trickling filters.

Q.71 (a)

BOD to be treated by oxidation pond = $150 - 15 = 135 \text{ ppm}$
 $\therefore \text{BOD}_5 = 135 \times 10^{-6} \times 5 \times 10^5 \text{ kg/day}$
= 67.5 kg/day

$$\text{Area of the pond} = \frac{67.5}{40}$$

$$= 1.6875 \text{ ha}$$

Q.72 (d)

In a totally aerobic pond, the stabilisation of wastes is brought about by aerobic bacteria, which flourish in the presence of oxygen. The oxygen demand of such bacteria in such a pond is met by the combined action of algae and other microorganisms (such as bacteria and protozoa*), called algal photosynthesis, or algal-symbiosis. In this symbiosis, the algae (which are microscopic plants) while growing in the presence of sunlight, produce oxygen by the action of photosynthesis; and this oxygen is utilized by the bacteria for oxidising the waste organic matter.

Q.73 (a)

An intercepting trap is often provided at the junction of a house sewer and a municipal sewer, so as to prevent the entry of the foul gases of the municipal sewer, into the house drainage system.

Q.74 (b)

A gully trap or a gully is often provided at the junction of a room or a roof drain and the other drain coming from bath, kitchen, etc.

Q.75 (a)

Soil pipe drains the night soil. Waste pipe drains sullage from baths etc. Antisiphonage pipe or a vent pipe to protect the water seals of traps.

Q.76 (b)

In this system, two sets of vertical pipes are laid, i.e., one for draining night soil, and the other for draining sullage. The pipes of the first set carrying night soil are called soil pipes, and the pipes of the second set carrying sullage from baths, are called sullage pipes or waste pipes. The soil pipe as well as the waste

pipe, are separately ventilated by providing separate vent pipes or antisiphonage pipes.

Q.77 (b)**Q.78 (d)**

Gully trap is provided at the junction of the room or a roof drain and the other drain coming from the bath, kitchen, etc. It may be P-trap or S-trap.

Intercepting trap is provided at the junction of a house sewer and a municipal sewer.

Water closets are fitted with P or S-trap.

Q.79 (c)**Q.80 (b)**

Rubbish includes combustible and non-combustible solid wastes.

Q.81 (b)**Q.82 (c)**

Incineration is the process of disposing of dewatered sludge by burning them in a furnace. Pulverisation is a technique of refuse disposal by grinding refuse to a lesser volume thereby changing its character.

Q.83 (c)

The leachate from sanitary landfill tend to pollute ground water. Incineration and pyrolysis release air pollutants. Composting does not have any harmful effect

Q.84 (d)

When sewage is applied continuously on a piece of land, the soil pores or voids may get filled up and clogged with sewage matter retained in them. Thus free circulation of air will be prevented and anaerobic conditions will

develop within the pores. Sewage sickness is the condition when soil pores get filled up and clogged with sewage matter due to continuous application of waste water effluents. This develops anaerobic conditions and foul gases like methane, carbon-dioxide and hydrogen sulphide are evolved.

In order to prevent sewage sickness:

1. Sewage should be given primary treatment
2. The soil chosen for effluent
3. A proper under drainage system (open jointed drains) should be designed.
4. Land should be given rest for some time and ploughed thoroughly.
5. Rotation of crops to be followed
6. Shallow depths of water should be applied.

Q.85 (c)

Sealeants are used of control for gas and leachate movement

| Classification | Representative types |
|------------------------|---|
| Compacted clay : | Bentonites, illites, kaolinites |
| Inorganice chemicals : | Sodium carbonate, silicate or pyrophosphate |
| Synthetic chemicals : | Polymers, rubber latex |
| Synthetic membrane : | PVC, butyl rubber, hypalon, polythene, nylon reinforced liners |
| Asphalt : | Modified asphalt, asphalt-covered polypropylene fabric, asphalt concrete. |
| Others : | Gunite concrete, soil cement, plastic soil cement |

The sealant material should be more impermeable than the soil. So sand will not be a suitable material. Flyash and lime themselves produce pollutants which dissolve in water. Therefore these materials cannot be used as sealants.

Q.86 (a)

Upon heating in a oxygen free atmosphere during pyrolysis, most organic substances can be split through a combination of thermal cracking and condensation reactions in gaseous liquid and solid fractions.

Q.87 (b)

Design loading rates for land application of biosolids can be limited by heavy metals or nitrogen. The annual loading rate is usually limited by nitrogen loading rate. The long-term loading rate is limited by heavy metals.

Q.88 (b)

Gases found in landfills include air, ammonia, carbon dioxide, carbon monoxide, hydrogen, hydrogen sulphide, methane, nitrogen and oxygen. Carbon dioxide and methane are the principal gases produced from the anaerobic decomposition of the organic solid waste components.

Q.89 (c)

Moisture content, $p_2=100-16=84\%$

We know that

$$V_1(100-p_1)=V_2(100-p_2)$$

$$\Rightarrow V_2 = 14 \times \left(\frac{100-94}{100-84} \right) = 5.25\text{m}^3$$

Q.90 (b)

Q.91 (b)

Ozone reacts with chlorine atom and gets breakdown into chlorine monoxide (ClO) and oxygen molecule.
 $\text{Cl} + \text{O}_2 \rightarrow \text{ClO} + \text{O}_2$

Q.92 (c)

Carbon monoxide affect human aerobic metabolism by forming carboxy – haemoglobin (CoHb). Oxides of nitrogen (NO_x) includes – nitric oxide (NO), nitrogen dioxide

(NO₂), nitrous oxide (N₂O), nitrogen sesquioxide (N₂O₃), Nitrogen tetroxide (N₂O₄) and nitrogen pentoxide (N₂O₅). NO and NO₂ are of primary concern as air pollutants. NO₂ plays major role in the production of secondary air pollutant ozone(O₃). SO₂ is responsible for acid rains as it combines with water vapour to form secondary pollutants like H₂SO₄ which cause acidity.

Q.93 (d)

The cumulative effect of these two noise levels will be between 90 dB and 94 dB.

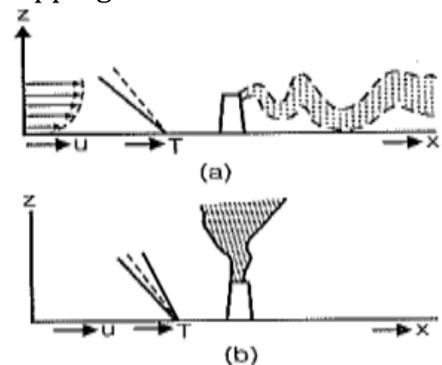
$$\begin{aligned} \bar{L}_P &= 20 \log \left[\frac{1}{N} \sum_{n=1}^N (10)^{L_n/20} \right] \\ &= 20 \log \left[\frac{1}{2} \times (10^{90/20} + 10^{94/20}) \right] \\ &= 92.2 \text{ dB} \end{aligned}$$

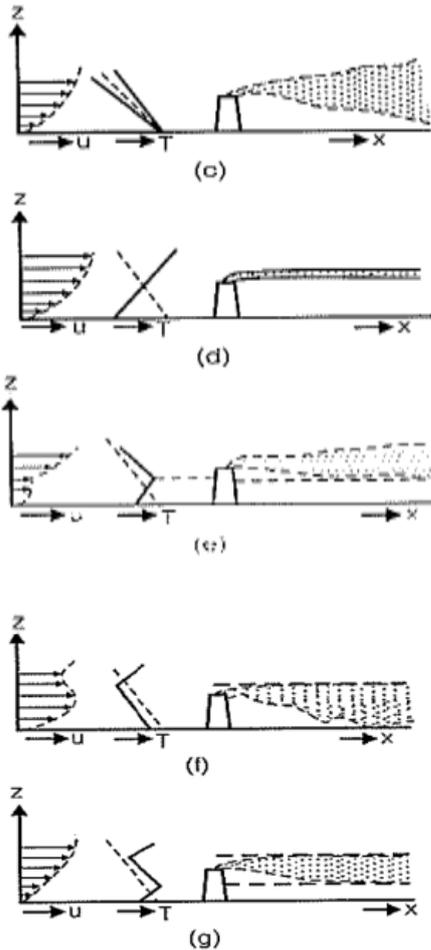
Q.94 (d)

1. When the ambient lapse rate is superadiabatic (greater than the adiabatic), the turbulence of the air itself causes the atmosphere to serve as an effective vehicle of dispersion. As indicated in fig-a, the resultant plume is designated as a looping plume.
2. When the ambient lapse rate is equal to or very near the dry adiabatic lapse rate, the plume issuing from a single chimney or smokestack tends to rise directly into the atmosphere until it reaches air of density similar to that of the plume itself. This type emission, called a neutral plume, is seen in fig-b.
3. When the ambient lapse rate is subadiabatic (less than the dry adiabatic), the atmosphere is slightly stable. Under such conditions, there is limited vertical mixing, and the

probability of air pollution problems in the area is increase. The typical plume in such a situation is said to be coning.

4. When the lapse rate is negative, as in the presence of an inversion, the dispersion of stack gas is minimal, because of lack of turbulence. In the extremely stable air, a plume spreads horizontally with little vertical mixing, and is said to be fanning (fig-d).
5. When the lapse rate is super-adiabatic above the emission source and inverse conditions exist below the source, the plume is said to be lofting. As shown in fig-e, a lofting plume has minimal downward mixing, and the pollutants are dispersed downwind without any significant ground-level concentrations.
6. When an inversion layer occurs at a short distance above the top of the stack and super adiabatic conditions prevail below the stack, then plume is said to be fumigation (fig-f).
7. When inversion layer exists above the emission source as well as below the source, then naturally, the emitted plume will neither go up, nor will it go down and would remain confined between the two inversion (fig-g). Such a plume is called a trapping.





SYMBOLS:

Adiabatic lapse rate _____

Environmental lapse rate _____

Q.95 (c)

Reverberation time is the time required to reduce the intensity to one-millionth of its initial value.

$$\text{Sound level(dB)} = 10 \log \left(\frac{I_1}{I_2} \right)$$

$$= 10 \log (10^6) = 60 \text{ dB}$$

TTS (Temporary Threshold Shift) is temporary impairment of hearing acuity as indicated by change in the threshold of audibility PTS (Permanent Threshold Shift) is related to permanent hearing loss. The sound foci are formed when sound waves are reflected from concave surface.

Q.96 (a)

Wind Speed $u = 4 \text{ m/s}$

Stack gas speed $V_s = 8 \text{ m/s}$

Diameter $d = 1 \text{ m}$

Heat rise $Q_h = 2000 \text{ kJ/s}$

We know that effective height of stack,

$$\Delta h = \frac{V_s \times d}{u} \left[1.5 + 0.0096 \times \frac{Q_h}{V_s \times d} \right]$$

$$\Delta h = \frac{8 \times 1}{4} \left[1.5 + 0.0096 \times \frac{2000}{8 \times 1} \right] = 7.8 \text{ m}$$

Q.97 (a)

| Name of mechanical device | Minimum particle size that can be removed | Efficiency |
|---|---|------------|
| Gravity settling chamber | > 50 μm | < 50% |
| Centrifugal collectors including cyclone collectors | > 5 - 25 μm | 50 - 90% |
| Electrostatic precipitators | > 1 μm | 95 - 99% |
| Fabric filters | < 1 μm | > 99% |

Q.98 (c)

Photochemically, the NO_x and hydrocarbons are two groups of chemical compounds which are the necessary ingredients for the production of photochemical smog.



The end product of photochemical reactions is photochemical smog consisting of air contaminants such as O_3 , PAN, aldehydes, ketones, alkyl nitrates and carbon monoxide.

Q.99 (b)

Electrostatic precipitator used for large industrial plants are high voltage single stage units. These are four steps in their working:

- i) Electrical charging of the particulates
- ii) Collection of charged particles on a grounded surface
- iii) Neutralization of the charge at

- the collector
- iv) Removal of the particulate for disposal

Q.100 (c)

Carbon monoxide (CO) combines with haemoglobin (Hb) of blood to give carboxy-haemoglobin (COHb), thus reducing the capability of the blood to carry oxygen. Since the affinity of haemoglobin for carbon monoxide is more than 200 times as great as its affinity for oxygen, CO can seriously impair the transport of O₂, even when present at low concentrations.