THEORY & OBJECTIVE

ENVIRONMENTAL ENGINEERING

By
Team of
Engineers Academy

- Covers ESE, GATE, IAS, PSUs, DRDO, ISRO & other Technical Exams.
- Covers complete syllabus & all topics of ESE & GATE examination.
- Thoroughly revised, fully solved & error free book.
- Concise, concept oriented and topicwise presentation & authentic solutions.

ENGINEERS ACADEMY®
Your GATEway to Professional Excellence
IES • GATE • PSUs • JTO • IAS • NET

CORPORATE OFFICE
100-102, Ram Nagar, Bambala Puliya, Tonk Road, Pratap Nagar, Jaipur-302033
Ph.: + 91-8094441777
Website : www.engineersacademy.org | Email: info@engineersacademy.org
Ajmer | Jaipur | Kota | Jodhpur | Bhilwara | Delhi | Patna | Lucknow | LPU | Ludhiana | Jalandhar | Kanpur | Allahabad

CONTENTS

S.No. Topic Page No.

1. Water Demand & Resources .... 1 – 12
2. Quality of Water .... 13 – 30
3. Water Purification .... 31 – 61
4. Filtration .... 62 – 81
5. Disinfection .... 82 – 92
6. Miscellaneous Water Treatments .... 93 – 102
7. Distribution System .... 103 – 127
8. Design of Sewers .... 128 – 149
9. Waste Water Characteristics .... 150 – 168
10. Treatment of Sewage .... 169 – 190
11. Sludge Digestion .... 191 – 203
12. Trickling Filters .... 204 – 216
13. Activated Sludge Process .... 217 – 231
14. Oxidation Ponds 232– 237
15. Disposing of The Sewage Effluents 238– 248
16. Solid Waste Management .... 249 – 256
17. Effect of Air Pollution .... 257 – 281
18. Sound Pollution .... 282 – 288

ENGINEERS ACADEMY
PUBLICATIONS
Log on to : www.eapublications.org | Ph. : 08094441777

1

WATER DEMAND & RESOURCES

THEORY

1.1 | WATER DEMAND

1.1.1 Domestic Water Demand

The total domestic water consumption usually vary from 50% to 60% of the total water supply to a city. The IS code list down a limit of water consumption between 135 to 225 ltr/capita/day (LPCD). Under ordinary condition (as per IS code) the domestic water demand for a town or a city with full flushing system should be taken as 200 LPCD. Although it can be reduced to 135 LPCD for economical weaker section and LIG colony.

1.1.2 Industrial Water Demand

This quantity varies with number and type of industries present in the city. This consumption under ordinary condition is 50 LPCD. Some industries influence a high water demand like : Paper industry, Textile industries etc.

1.1.3 Institutional and Commercial Water Demand

On an average demand is 20 LPCD. It may be as high as 50 LPCD.

1.1.4 Demand for Public Use

This includes water requirement for parks, gardening washing of roads etc. On this account a normal amount not exceed 5% of consumption may be provided.

1.1.5 Fire Demand

The quantity of water require for fire is not very large. The city upto 50 lakh population hardly amount is 1 LPCD. But this water should be easily available and kept always stored in storage reservoir.

1.1.6 Water Demand for Losses & Theft

This may be as high as 15% of total demand.

1.2 | FACTORS AFFECTING WATER DEMAND

(a) Size of city
(b) Climate condition
(c) Industrial and commercial activities
(d) Habits of people
(e) Quality of water supply
(f) Pressure in the distribution system.
(g) Development of sewage facility.
(h) Cost of water and method of charging.

1.3 | POPULATION FORECASTING METHODS

Methods are based on laws of probability and growth curve. Following are population forecasting methods :

(a) Arithmetic increase method
(b) Geometric increase method
(c) Incremental Increase method
(d) Decreasing rate of growth method
(e) Simple graphical method
(f) Comparative graphical method
(g) Master plan method or zoning method
(h) The ratio method or apportionment method
(i) The logistic carve method

Methods are Discussed Below:

(a) Arithmetic Increase Method

This method assumes that the population increases at a constant rate :

$$\frac{dP}{dt} = \text{constnat}$$

Forecasted population (P_n) after 'n' decades

$$P_n = P_0 + n\bar{x}$$

where,

P_0 = Population at last known census.
$\bar{x}$ = Average (Arithmetic mean) of population increase in last decades.
n = No. of decades between last census and future.

(b) Geometric Increase Method

It is also known as 'uniform increase method'.

Forecasted population,

$$P_n = P_0\left(1+\frac{r}{100}\right)^n$$

where,

P_0 = Population at last known census.
r = Growth rate (%)

$$r = \frac{\text{Increase in population}}{\text{Orginal population}} \times 100 \text{ for each decade.}$$

Knowing as r_1, r_2, r_3, r_4 .... r_n for each decade.

The average value of r can be found by

(i) Arithmetic average method

$$r = \frac{r_1 + r_2 + r_3 + \ldots\ldots\ldots. r_n}{n}$$

(ii) Geometric average method

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

Note: *Engineers adopt arithmetic average method since it gives more value than the geometric avg. Method. However GOI manual on water supply recommends 'Geometric mean method'.*

(iii) Incremental increase method:

Rate of growth is not assumed constant.

Population

$$P_n = P_0 + n\bar{x} + \frac{n(n+1)}{2}\bar{y}$$

where,

P_0, n, $\bar{x}$ are as usual.

$\bar{y}$ = Average of Incremental increase of the known decades.

Note: (i) *Geometric mean method suitable for younger cities expanding of faster rate.*

(ii) *Incremental increase method suitable for both old and new cities.*

Example: The population of 5 decades from 1930 to 1970 are given below in table. Find out the population after '3' decades beyond the last known decade, by using

(i) Arithmetic mean method (ii) Geometric mean method (iii) incremental increase method

Year	1930	1940	1950	1960	1970
Population	25000	28000	34000	42000	47000

Solution:

Col (1)	Col (2)	Col (3)	Col (4)	Col (5)
Year	Population	Increase in population	Growth rate (r) %	Incremental increase
1930	25000			
		3000	$\frac{3000}{25000}\times 100 = 12$	
1940	28000			6000-3000 = 3000
		6000	$\frac{6000}{28000}\times 100 = 21.4$	
1950	34000			8000-6000 = 2000
		8000	$\frac{8000}{34000}\times 100 = 23.5$	
1960	42000			5000-8000 = -3000
		5000	$\frac{5000}{42000}\times 100 = 11.9$	
1970	47000			
Total		Σ = 22000		Σ = 2000

(i) Arithmetic mean method:

$$\bar{x} = \frac{\sum col(3)}{4} = \frac{22000}{4} = 5500$$

$$P_{2000} = P_{1970} + n\,\bar{x}$$

$$= 47000 + 3 \times 5500 = \mathbf{63500}$$ **Ans.**

(ii) Geometric mean method :

(a) $$r = \frac{r_1 + r_2 + r_3 + r_4}{4} = \frac{12 + 21.4 + 23.5 + 11.9}{4} = 17.2\%$$

$$P_{2000} = P_{1970}\left(1 + \frac{r}{100}\right)^n$$

2

QUALITY CONTROL OF WATER

THEORY

Water impurities are classified on the basis of following properties

1. Physical Parameter **2.** Chemical Parameter **3.** Biological Parameter

2.1 PHYSICAL PARAMETER

1. Suspended solids

2. Turbidity

3. Taste and odour

4. Colour

5. Temperature

1. Suspended Solids

Source : These are called as physical parameters where as dissolved solids are considered as chemical parameters. SS 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 but not in groundwater.*

Objection : These are objectionable because :

- Aesthetically displeasing,
- It provides adsorption sites for chemical and biological agents
- 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 done as filterable and non-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 solids can be determined by firing the residue at 650°C.

$$\text{Organic fraction} \xrightarrow{650°C} CO_2 + \text{Water} + \text{Other gases}$$

Remaining solids are inorganic solids or fixed solids.

➢ ***The permissible limits :***

❖ For suspended solid as per EPA is 30 mg/l

2. Turbidity:

➢ ***Definition :*** 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 :

(a) Turbidity rod
(b) Jackson's turbidimeter
(c) Baylis turbidimeter
(d) Nephelometer

(a) Turbidity Rod

Rod with platinum needle is inserted inside water and the depth at which platinum needle just becomes invisible gives turbidity in ppm. Turbidity which one milligram of finely divided silica produces in one litre of distilled water is taken as one unit. The permissible limit is 5 - 10 ppm. It is a fields method**.**

Note: *Government of India manual gives turbidity in NTU i.e. Nephelometer turbidity unit. Acceptable limit is 1 and cause for rejection is 10.*

(b) Jackson's Turbidimeter :

❖ 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.

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

(c) Baylis Turbidimeter and Nephelometer :

Baylis and Nephelometer turbidimeters 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 at right angles to the incident ray. Hence NTU is based on scattering principle. If Formazine, a chemical, is used as base in place of SiO_2. The turbidity unit is also sometimes called FTU.

3. Taste and Odour

Taste and odour are caused by dissolved gasses like H_2S (Hydrogen sulphide), mercaptans, methane organic matter derived from certain dead or living micro organism, decomposing organic matter, industrial liquid, water 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. 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 odourus water in mL and B is the volume of odour free water required to produce a mixture in which odour is hardly detectable. Odours 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, flock or clays.

4. 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 oxidised 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 dying 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 colour produced by 1 mg per litre of platinum in the form of chloroplatinate ion (It is only for yellowish brown colour). 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 effluent biological or physical properties may change.

- ***Permissible limit :*** Acceptable limit is 5 TCU and cause for rejection is 25 TCU

5. Temperature :

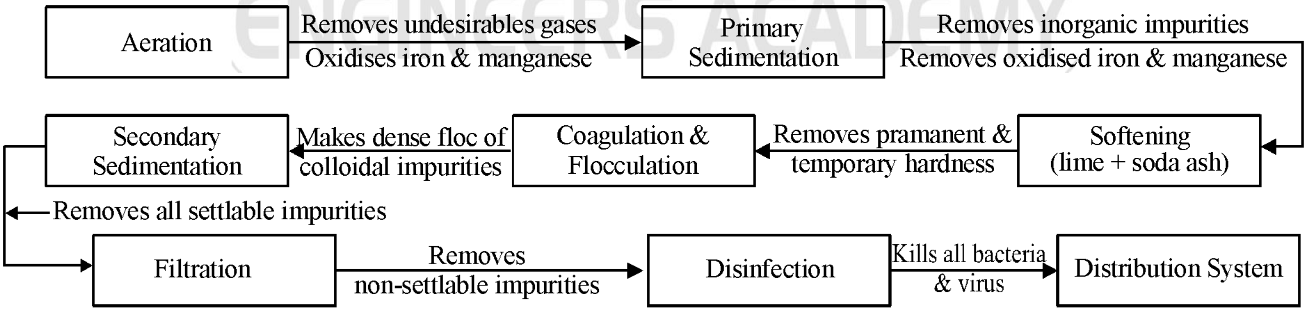
Temperature affects the chemical and biological reactions. An increase in 10°C, doubles the biological activity. Hence for water supply, the temperature should be between 10-25°C and greater than 25°C is objectionable.

3

WATER PURIFICATION

THEORY

- Method of treatment employed depends on the nature of raw water constituents and the desired standard of water quality.
- The treatment process is also depended on the uses of water. For examples
  - (a) ***Boilers :*** Zero or minimum hardness
  - (b) ***Paper Industries :*** Colour free, Iron, Magnesium free
  - (c) ***Drinking Purpose :*** Should stasified all water quality parameters.
- The unit operations in water treatment includes
  - Screening
  - Coagulation & Flocculation
  - Filtration
  - Aeration
  - Softening
  - Deferrization
  - Sedimentation
  - Disinfection
  - Defluoridation
- The choice of a particular sequence of treatment unit will depend on quality of raw water and treated water desired.
- In case of ground water and surface water with storage having turbidity less than 10 NTU and free from colour, odour, plain disinfection is sufficient for drinking purposes.



Typical flow diagram of all processes

- For ground water containing excessive iron, dissolved carbon dioxide and odourous gas; the treatment process will be

Aeration → Flocculation + Sedimentation → Rapid gravity → Disinfection → Supply

- If ground water contains only CO_2 and odourous gases, aeration and disinfection is sufficient.
- Surface water with turbidity less than 50 NTU and where sufficient land is available, the treatment will be

sedimentation + slow sand filter + Disinfection

- Highly polluted surface water laden with algae and other microorganisms the sequence of treatment will be

Screening + Prechlorinate + aeration + Flocculation and sedimentation + Rapid gravity filteration + Disinfection (postchlorination) + supply

- **Typical Plant Treating Hard Ground Water :**

It is similar to the typical flow diagram escape primary sedimentation process. It serves following purpose:

  - It removes undesirable gases
  - It oxidises iron and manganese
  - It removes calcium and magnesium hardness
  - It removes residual $CaCO_3$ and $Mg(OH)_2$ left over from softening
  - Disinfectant may be added to prevent biological growth on filter medium
  - It destroys the pathogenic bacteria and amount should be sufficient so that residual remain in the distribution system.

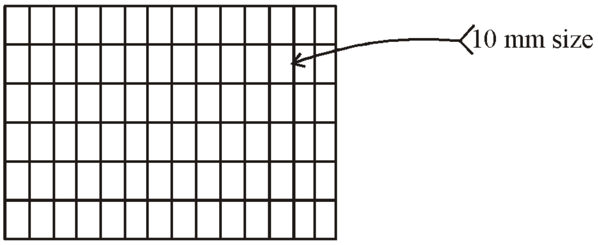
- **Treatment Plant Treating Turbid Surface Water with Organics :**

It is similar to the typical flow diagram escape primary sedimentation, softening process. It serves following purpose:

  - It may be necessary when water comes from fast flowing streams. It removes large suspended solid
  - Chemical may be added to oxidise organics
  - It removes turbidity by coagulating colloids and settling the out flow.
  - It may also remove colour caused by large organic molecules
  - It polishes the water and removes remaining turbidity
  - It may be necessary if water contains dissolved organics. The unit may consist of activated carbon added in powdered from in operation similar to mixing, flocculation and settling.
  - It destroyed pathogen and enough quantity of chlorine is added to provide residual in the distribution system.

3.1 | SCREENING

These are classified as coarse screen and fine screen. Coarse screen are in the form of bars spaced at 20-50 mm c/c. It is kept inclined 45° to 60° H for increasing flow area and to reduce velocity. smaller velocity also help in racking. Coarse screen is sometime also called Thrash rack. Fine screen is in the form of wire mesh with opening less than 10 mm size. As the fine screen gets clogged easily, head loss increases. Hence we try to avoid fine screen. Fine particles may be settled in the sedimentation tank.



➢ ***Microstrainer :***

❖ 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 or slow sand filters whose efficiency is increased by approx 50%.

3.2 | AERATION

Water is bought in intimate contact with air. It is used to remove undesirable gases dissolved in water like CO_2, H_2S. 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 $Fe^{2+}$and Mn^{2+} form. They are oxidised to $Fe(OH)_3$and MnO_2which precipitates

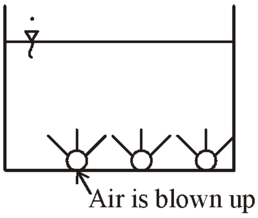
$$4Fe^{2+} + O_2 + 10H_2O \rightarrow 4\,Fe(OH)_3 \downarrow + \boxed{8H^+}$$

$$2Mn^{2+} + O_2 + 2H_2O \rightarrow 2MnO_2 \downarrow + \boxed{4H^+}$$

❖ This processes increases the acidity of water

❖ Process of aeration

- ✪ Spray nozzle → Removes 90% CO_2 and 99% H_2S.
- ✪ Cascade aerator → 60 – 70% CO_2 and 35% H_2S.
- ✪ Diffused air aerator →



4

FILTRATION

THEORY

- Filtration removes fine floc particles, colour, dissolved minerals and microorganisms.
- It also removes the suspended solids that does not get removed in sedimentation.
- Filters are classified as:
  - (a) Slow sand filter
  - (b) Rapid sand filter
  - (c) Pressure filter

Note: Slow sand filter and Rapid sand filter are working under gravity force. The pressure head available for filtration is provided by a height of water above the sand bed.

In pressure filter head is provided by pressure mechanism.

- 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.

Theory of Filtration

1. Mechanical Straining
2. Sedimentation
3. Electrolytic changes
4. Biological action

1. Mechanical Straining

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

2. Sedimentation

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

3. Electrolytic Changes:

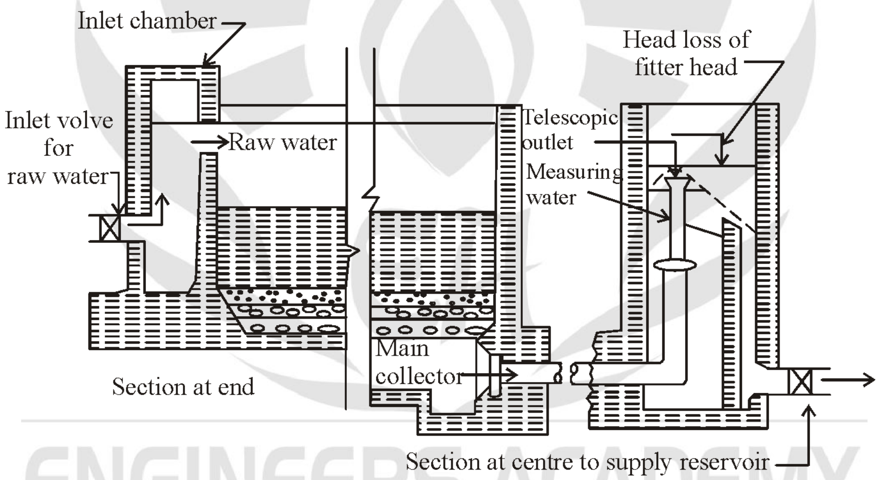
- Sand grains in filter and impurities in water carry opposite charges. Thus because of their interaction, chemical characteristics of water changes and it becomes pure.

- During washing process of filter neutralized material is removed.

4. Biological Metabolism

- Certain micro organisms and bacteria are generally present in the voids of the filters. They either reside initially as coating over sand grains or they may be caught during the initial process of filtration. These bacteria utilise finely divided suspended material like :- plankton and other organic material and deposite it on the top layer of filter. This layer is called the "Schmutzdecke" or dirty skin and it acts as an extremely fine meshed straining mat.
- A few millimeters below the schmutzdecke zone is the zone known as autotrophic zone. In this zone, the growing plant life breaks down organic matter, decomposes the plankton and used available nitrogen, phosphates and carbon dioxide providing oxygen in their place. The filtrate becomes oxidised at this stage.
- A few millimeters below the autotrophic zone, the heterotrophic zone extends around 300 mm into the bed. In this zone, the bacteria multiply to very large numbers and the breakdown of organic matter is completed and the resulting effluent consists of simple inorganic substances and unobjectionable salts.
- The bacteria act not only to break down organic matter but also to destroy each other and so tend to maintain a balance of life native to the filter so that the resulting filtrate is uniform.

4.1 | SLOW SAND FILTER



It utilizes the effluent from plain sedimentation tank only, which is relatively clearer. Depth of tank is 2.5 to 3.5m. Plan area required is 100 – 2000 m^2. Filter medium is sand or anthracite or garnet. D_{10} (of filter medium) = 0.2 – 0.4 mm. $\frac{D_{60}}{D_{10}}$ = uniformity coefficient = 1.8 to 2.5 Depth of sand is 90 – 110 cm. 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.

Base 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.

➢ **Operation:**

- Filtering action mostly takes place at or near the surface of the sand. At the surface a mat (schmutzdecke as explained earlier) rapidly builds up, the filter becomes ripe and filtration continues for a period of about a month before cleaning. As the rate of flow is low, the loss of head is small varying between about 5 cm when the filter is clean to about 90 cm when it is dirty.
- The increased head required or provided by adjusting the outlets so as to raise the head available over the sand. When the filter loses around 0.8 to 0.9 times of sand bed depth, it is taken out of service, drained and the top 15 mm of sand is scraped off and removed and washed.
- The filter is then returned to service slowly in order to permit the Schmutzdecke to re-form. After several scrapings, the sand bed becomes too thin (around 60 cm) and it has to be restored to its original thickness of 90 cm by replacement of the sand removed.
- This is generally the same sand that is removed after getting dry and washed and stored near the filter. After a period of several years of use, the bottom sand in the filter tends to turn black and septic and the bed is dug out and removed.

➢ **Clearning of Filter**

- For cleaning, the top layer of sand is scraped and 1.5 to 3 cm of sand is removed in each cleaning.
- Filter is washed with good water.
- Washed filter is then loaded with raw water but effluent is not used.
- After 24 – 36 hrs. a film of arrested impurities forms and the filter become ready for operation.
- The frequency of cleaning is 1 – 3 months.
- Rate of filtration is 100-200 l/hr/m^2 of filter area.
- Efficiency of slow sand filter in bacteria removal is 97-98.%
- If the water is prechlorinated, efficiency can go upto 99.5-99.9%.
- This filter cannot be used if turbidity is greater than 50 ppm.
- It is less effective in removing colour but better in removing algae than coagulation + rapid sand filters.
- The effluent from slow sand filter contains less nutrients (nitrogen and phosphorous) and has reduced possibility of after growth of organisms in distribution system.
- It is used for smaller plants in villages.
- It is designed for maximum daily demand.
- Number of beds of filter required depend on are i.e.

Upto 20 m^2 area → 2 No. S $(\overset{\text{Operational}}{1} + \underset{\text{Stand by}}{1})$

20 – 249 m^2 → 3 No. S (2 + 1)
250 – 649 m^2 → 4 No. S (3 + 1)
650 – 1200 m^2 → 5 No. S (4 + 1)
1201 onwards → 6 Nos S (5 + 1)

➢ **Under Drainage Arrangement :**

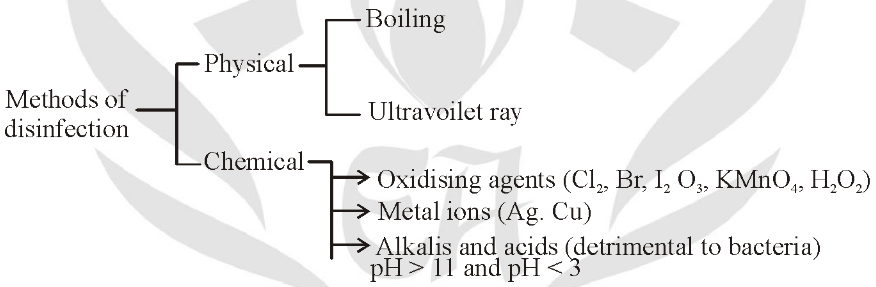
- The base of sand bed consisting of gravels is laid on the top of an under-drainage system. This consists of a central drain connected with lateral drains as shown in Figure. The laterals are open jointed pipe drains placed 3 to 5 m apart at the floor sloping towards the main central drain.

5

DISINFECTION

THEORY

- ❖ Disinfection may be defined as the process of distruction 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.

5.1 | MINOR METHODS

5.1.1 Treatment with Ozone

$$O_3 \rightarrow O_2 + \underset{\substack{\text{Nascent}\\\text{oxygen}}}{O}$$

- ❖ Nascent oxygen is a powerful oxidising 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 taste to water.

- It does not ensure safety against future recontamination.
- It is less efficient than chlorine in killing bacteria.

5.1.2 *Treatment with KMnO$_4$*

It is a popular disinfectant for well water supplies in villages which are contaminted with lesser amount of bacteria. Besides killing bacteria, it also helps in oxidising the taste producing organic matter, hence it is sometimes added to even filtered chlorinated water. Dose 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 $KMnO_4$ with passage of time produces dark brown precipitate. This agent is mostly used in rural areas. Provide pink colour when added if colour disappears, it indicates presence of micro-organism, hence more $KMnO_4$ is added until pink colour stand. Water is not used for 48 hours.

5.1.3 *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.

5.1.4 *Treatment with I$_2$ and Br$_2$*

They are available in the form of pills.

5.2 | MAJOR METHODS

5.2.1 *Chlorination*

$$Cl_2 + H_2O \xrightleftharpoons{pH>5} HOCl + HCl; \quad \underset{\substack{\text{Unstable hence}\\ \text{break downt}\\ \text{at higher pH}}}{HOCl} \xrightleftharpoons[pH<7]{pH>8} H^+ + OCl^-$$

- At pH < 5, chlorine does not react with water and remains as free chlorine.
- ($HOCl + OCl^-$ and Cl_2) 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.

$$NH_3 + HOCl \xrightarrow{pH>7.5} NH_2Cl + H_2O$$

$$NH_2Cl + HOCl \xrightarrow{pH(5-6.5)} NHCl_2 + H_2O,\ pH\ (5 - 6.5)$$

$$NHCl_2 + HOCl \xrightarrow{pH<4.4} NCl_3 + H_2O,\ pH < 4.5$$

- Chloramines are combined form of chlorine. It is less effective than free chlorine (25 time lesser). But they are stable and remains in water for greater duration.
- In the usual chlorine treatment, in which pH is kept slightly less than 7, dichloramine is most predominant.
- 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 dose is called chlorine demand of water.
- The residual chlorine is tested by DPD (Diethyl-Paraphenylene diamine) test.

Forms in which chlorine is Added

- As free chlorine (liquid or gaseous form).
- Hypochlorites (Bleaching powder).
- Chloramines (ammonia + chlorine).
- Chlorine dioxide (ClO_2).

5.2.2 *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°C. 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 underloading and overloading is less frequent. Chlorine is a powerfull 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.

5.2.3 *Hypochlorite or Bleaching Powder ($Ca(OCl)_2$)*

$$Ca(OCl)_2 \rightleftharpoons Ca^{2+} + \underset{\substack{\text{Hypochlorite}\\ \text{ion}}}{2OCl^-} ; \quad OCl^- + H^+ \underset{pH>8}{\overset{pH<7}{\rightleftharpoons}} HOCl$$

Hypochlorite or Bleaching Powder ($Ca(OCl)_2$, 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. 1.42 gm of $Ca(OCl)_2$ will contain 1.02 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 loosing 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.

$$CaCl_2 \cdot Ca(OH)_2 \cdot H_2O + Ca(OC)_2 \cdot 2Ca(OH)_2$$

5.2.4 *Use of Chloramines*

Chloramines 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 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 chloramine 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.

5.2.5 *Chlorine Dioxide (ClO_2)*

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

$$2NaClO_2 + Cl_2 \longrightarrow 2NaCl + 2ClO_2$$

(ClO_2 is highly unstable hence should be used immediately after production)