UNIT – III

Theory of filtration:

Process of passing of water through the beds of granular materials is known as filtration. The filters in fact, purify the water under four different processes.

1. **Mechanical straining:**

   The suspended particles present in water and which are of bigger size than the size of the voids in the sand layers of the filters, cannot pass through these voids and get arrested in them. The resultant water will, therefore, be free from them.

   Most of the particles are removed in the upper sand layers. The arrested particles including the coagulated flocs forms a mat on the top of the bed, which further helps in straining out the impurities.

2. **Flocculation and Sedimentation:**

   It has been found that the filters are able to remove even particles particles of size smaller than the size of the voids present in the filter. This fact mat be explained by assuming that the void spaces act like tiny coagulation sedimentation tanks. The colloidal matter arrested in these voids is a gelatinous mass and therefore attract other finer particles. These finer particles does settle down in the voids and get removed.

3. **Biological metabolism:**

   Certain micro-organisms and bacteria generally present in the voids of the filters. They may either reside initially as coatings over sand grains or they may be caught during the initial process of filtration. Nevertheless these organisms require organic impurities as their food for their survival. These organisms therefore utilize such organic impurities and convert them into harmless compounds by the process of biological metabolism. These harmless compounds so formed, generally form a layer on the top, which is called schmutzdecke or dirty skin. This layer further helps in absorbing and straining out the impurities.

4. **Electrolytic changes:**

   The purifying action of filter can also be explained by the theory of ionisation. According to this theory, a filter helps in purifying the water by changing the chemical characteristics of water. This may be explained by the fact that sand

grains of the filter media and the impurities in water, carry electrical charges of opposite nature. They neutralize each other, thereby changing the character of the water and making it purer. After a certain interval, the electrical charges of sand grains get exhausted and have to be restored by cleaning the filter.

Types of filters:

Filters are of three types. They are:

1. Slow sand filters
2. Rapid sand filters
3. Pressure filters

When classification based on rate of filtration, the filters can be divided as follows.

```
                          Filters
                             |
            ┌────────────────┴────────────────┐
      Slow sand filters              Rapid sand filters
                                              |
                                 ┌────────────┴────────────┐
                          Rapid sand filters        Pressure filters
```
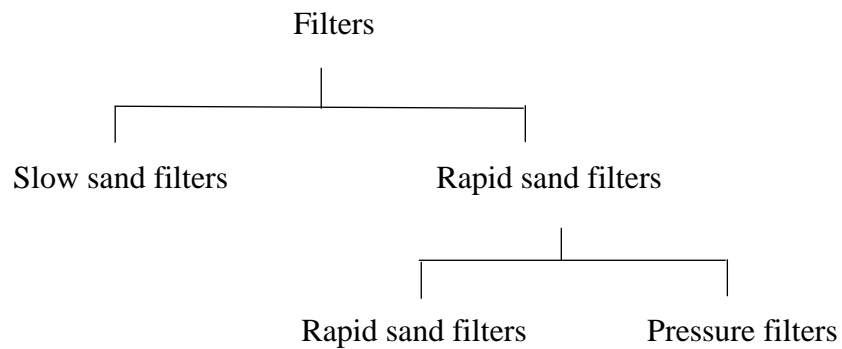
Similarly, classification based on gravity and pressure, the filters can be divided as follows.

```
                          Filters
                             |
            ┌────────────────┴────────────────┐
       Gravity filters                Pressure filters
                                              |
                                 ┌────────────┴────────────┐
                          Slow sand filters          Rapid sand filters
```
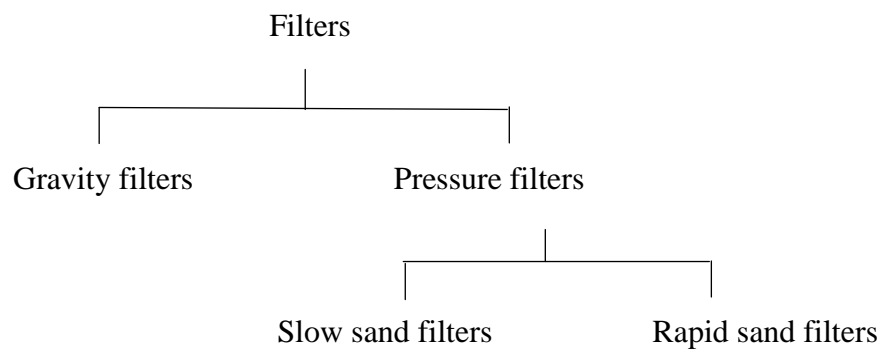
Slow sand filters (SSF):

Construction of SSF:

1. **Enclosure tank:**

- It consists of an open water – tight rectangular tank, made of masonry or concrete, made of masonry or concrete.

- Bed slope is kept at about 1 in 100 towards the central drain.
- Depth of tank – 2.5 to 3.5 m.
- Area of tank may vary – 100 to 2000 m^2. Depending upon the quantity of water to be treated.

2. **Filter Media:**

- Sand should be free from dirt, organic matter and Suspended matter.

- It should be hard and resistant.

- Finer the sand particles, finer will be the particles to be removed, purer will be the water.

- Effective size (D_{10}) varies from 0.2 to 0.4 mm.

- Uniformity coefficient varies from 1.8 to 2.5 or 3.0

- Depth of sand varies from 90 to 110 cm.

- Increased effective size, decreased uniformity coefficient void space increases, rate of filtration increases.

- Different gradations of sand are used, then the coarsest layer should be placed near the bottom layer and the finest at the top.

3. **Base Material:**

- Base material is gravel, and it supports sand.

- It consists of 30 to 75 cm gravels of different sizes, placed in layers.

- Generally 3 to 4 layers. Each layer of 15 to 20 cm depth. The coarsest gravel should be placed near the bottom layer and the finest gravel at the topmost layer.

- Size of gravel in the bottom – most layer is generally 40 to 65 mm, in the intermediate layers 20 to 40 mm and 6 to 20 mm and in the top layer as 3 to 6 mm.

4. **Under Drainage System:**
    - Gravel support is laid on the top of an under drainage system. The under drainage system consists of a central drain and lateral drains.
    - The laterals are open jointed pipe drains or some other kind of porous drains placed 3 to 5 m apart on the bottom floor and sloping towards a main covered central drain.

- These laterals collect the filtered water and discharge it into the main drain, which leads the water to be filtered well.

5. **Inlet and outlet arrangements:**

- An inlet chamber is constructed to admit the effluent from plain sedimentation tank without disturbing the sand layers of the filter and to distribute it uniformly over the filter bed.
- Filtered water well is constructed on the outlet side, to collect the filtered water coming out from the main drain.
- To maintain constant discharge, an adjustable telescopic tube is used.
- Inlet and outlet arrangements are generally governed by automatic valves.

Working of SSF:

- The effluent from plain sedimentation tank is allowed to enter the inlet chamber and get uniformly distributed over the filter bed.
- Water percolates through the filter media and gets purified during the process of filtration.
- The water now enters the gravel layers and comes out as the filtered water and filtered water is collected by the laterals through the open joints, finally discharges into the filtered water well, from where it can be taken to the storage tank for supplies or for further treatment.
- To maintain constant discharge, an adjustable telescopic tube is placed.
- Cleaning of SSF is done by scrapping and removing the 1.5 to 3 cm of top sand layer.
- When a newly constructed or freshly cleaned filter unit is put in operation, resistance offered by sand grains to the flow of water through it is usually small, say 10 to 15 cm.
- As solids arrested this loss of head reaches the maximum permissible value 70 to 120 cm, filter must be cleaned, by scrapping the top layer for a depth of 3cm, wash and is then stored.
- For each cleaning some depth of sand is removed due to which the effective depth of filter medium goes on decreasing, this process is continued until the thickness of medium reaches the minimum value of 60cm.
- Then filtered bed is toped up with the new sand or old washed sand to its original level.

- Period of cleaning is 1 to 3 months depending upon thro impurities in water.
- Is then allowed to stand for atleast 12 hrs, help in formation of biological film there after run its normal.
- Highly effective in removal of bacterial load (98 – 99%)

Rapid sand filters (RSF):

- The basic defect in SSF is its low filtration rate, due to which larger area is required.
- RSFs are developed in U.S.A during the period of 1900 – 1910 usually smaller in size and higher filtration rate (30 times) hence most commonly used in water supply projects.

Construction of SSF:

1. **Enclosure tank:**
   - It consists of an open water – tight rectangular tank, made of masonry or concrete, made of masonry or concrete.
   - Depth of tank varies from 2.5 to 3.5 m.
   - To achieve uniform distribution area of filter units should not be kept larger. It's area is limited to 10 to 80 m^2.
   - Number of units at a filter plant may be roughly estimated by equation developed by Morrell and Wallace.

$$N = 1.22 \sqrt{Q}$$

   Where N = No. of units

   Q = Plant capacity in MLD

   - There should be at least 2 units in any plant. If capacity exceeds 9MLD, no single unit have 1/4rth of its capacity

2. **Filter Media:**

- Sand should be free from dirt, organic matter and Suspended matter.

- It should be hard and resistant.

- Finer the sand particles, finer will be the particles to be removed, purer will be the water.

- Effective size (D_{10}) varies from 0.35 to 0.55 mm.

- Uniformity coefficient varies from 1.3 to 1.7

- Depth of sand varies from 60 to 90 cm.

- Different gradations of sand are used, then the coarsest layer should be placed near the bottom layer and the finest at the top.

3. **Base Material:**

- Base material is gravel, and it supports sand.

- Addition to the support of sand, it distributes the wash water.

- It consists of 60 to 90 cm gravels of different sizes, placed in layers.

- Generally 5 to 6 layers. Each layer of 10 to 15 cm depth. The coarsest gravel (40 mm size) should be placed near the bottom layer and the finest gravel (about 3 mm in size) at the topmost layer.

- Size of gravel in the bottom most layer is generally 20 to 40 mm, in the intermediate layers 12 to 20 mm and 6 to 12 mm and in the top layer as 3 to 6 mm.

4. **Under Drainage System:**
   - Gravel support is laid on the top of an under drainage system. The under drainage system consists of a central drain and lateral drains.
   - Under drainage system is for 2 purposes.
     1. To receive and collect the filtered water.
     2. To allow the back washing for cleaning the filter.
   - It should be designed in such a way that in addition to collecting the filtered water during its downward movement, it should be capable of passing the wash water upward at a high rate of 300 to 900 lit/min/m^2 of filter area.
   - Various forms of under drainage system are:
     1. Manifold and lateral system
     2. Pipe and strainer type system
     3. Wheeler system
     4. Leopald system
     5. Wagner system

Manifold and Lateral System:

- This type of installation consists of 40 cm dia. manifold pipe running length wise along the centre of filter bottom.
- 10 cm dia laterals are used which are right angles to the manifold pipe.
- Laterals are spaced 15 – 30 cm apart.

Perforated pipe type system:

- Laterals are provided with holes at the bottom side.
- Holes of dia. 6 to 13 mm, with an angle of 30° with vertical.
- Holes are spaced 7.5 to 20 cm c/c for 6 to 13 mm dia. Pipes.
- They may be staggered on either side instead of being continuous. Brass brushings are sometimes inserted in these holes, so as to avoid the rusting of surfaces of holes.
- Drains are supported on concrete blocks of about 40 to 50 mm tk.
- For back washing it requires 700 - 800 lit/min/sq.m of wash water is required (high velocity wash)

Pipe and Strainer System:

- In this system, the laterals are attached to the manifold pipe but in place of drilled holes, strainers are placed.
- Strainer is a small brass pipe closed at its top by a perforated cap.
- Strainers are placed 15 cm apart on lateral drain.
- Compressed air is used while back washing. To save wash water.
- When strainers are used wash water required is 250 – 300 lit/min/sq.m (slow velocity wash)
- Compressed air assists in agitation of sand particles.

The following points may also be considered and kept in mind, while designing the sizes of the pipes to be used in the above system.

1. Ratio of L to D should not exceed 60
2. Ratio of total area of perforations in the UDS to total c/sectional area of laterals should not exceed 0.5 (for 12 mm perforations) and should decrease 0.25 (for 5 mm perforations).
3. Total c/s area of perforations should be 0.2% - 0.3% of total filter area.

4. C/S area of each lateral should be 2 – 4 times the total c/s area of perforations.

5. C/S area of manifold should be 1.5 - 2 times the c/s area of lateral drains.

6. Max. permissible velocity in the manifold – 1.8 to 2.4 m/sec.

5. Other appurtenances:

    1. Wash water troughs

    2. Air compressor

    3. Rate controller

    4. Miscellaneous accessories

1. Wash water troughs:

- To collect dirty wash water, bottom of trough is placed on the top of the expanded sand (5 cm).

- Upper edge of trough kept nearer to the surface of the sand, large quantity of dirt water is collected.

- Square, V shape or semi-circular shaped troughs are used.

- These troughs may be of cast iron, concrete, steel or wrought iron.

- Trough should be large enough with FB of 6 – 8 cm.

- Spacing of wash water trough – 1.5 to 2 m.

2. Air Compressor:

- During back washing the filter, sand grains are agitated either by water jet, compressed air or by mechanical rakes.

- When compressed air is used, air compressor unit having the required capacity must be installed.

- Generally it should supply air for 4 minutes or so, at a rate of 600 to 800 lit/min/sq.m of filter area..

- Pressure of compressed air should sufficient to overcome the frictional resistance overcome by the air pipes.

- Compressed air supply either by laterals or by separate system.

3. Rate controller:

- In order to obtain automatically, a uniform rate of filtration irrespective of the head loss through the filter, rate controllers are required to be fitted at the outlet end of each filter unit.

- Most commonly used type of controller is a Venturi –rate controller.

- Sudden increase in filtration – water to break through filter material without proper treatment.
- Sudden decrease in filtration – may release a bubble of gas entrained in sand, causing it to make a hole through the filter bed. For uniform rate, rate controllers are used.

4. Miscellaneous Accessories:

- Head loss indicator, meters for measuring rates of flow etc., are also needed. Meters are installed for measuring discharges at the entry and outlet, also at back wash.

Working and cleaning of RSF:

- Valve 1 is opened, which leads the effluents of the coagulation sedimentation basin, to enter the inlet chamber of the filter. This water gets filtered through the filter beds and filtered water can be taken by opening main drain valve 4.
- When sand becomes dirty, indicated by excess loss of head, filter must be cleaned and washed.
- For cleaning raw water supplies as well as filtered water supplies have to be cut off, bed drained down, and wash water sent back upward through the filter beds.
- Valve 1 and 4 are closed, valves 5 and 6 are opened. The wash water and compressed air are thus forced upward from the under- drainage through the gravel and sand beds.
- Valve 5 is closed after supplying sufficient amount of air.
- The dirty water resulting from washings, overflows into the wash water troughs and is removed by opening the valve 2 through the inlet chamber into the gutter.
- Process of washing and removing the dirty water continued for a period of 3 to 5 min.
- After washing of filter, valves 2 and 6 will be closed. Valves 1 and 3 are opened. Inlet supplies water through valve 1, but the filtered water in the beginning is not collected and washed for a few minutes through valve 3 to gutter.
- This is necessary because the remains of wash water must be removed from the voids and a surface mat must be allowed to be formed on sand.
- Valve 3 is closed and valve 4 is opened to get the filtered water again.
- Entire process of backwashing the filters and re-maintaining filtered supplies takes about 15 min. filtered unit will be remained out of operation for this much time.

- Amount of water required for backwashing is 2 to 5% of filtered water. RSFs gets frequently clogged and have to be washed every 24 to 48 hrs.
- Rate of washing may vary between 15 – 90 cm rise per min.
- Bacterial load removal efficiency is 80 to 90 % and remaining are removed in disinfection units.
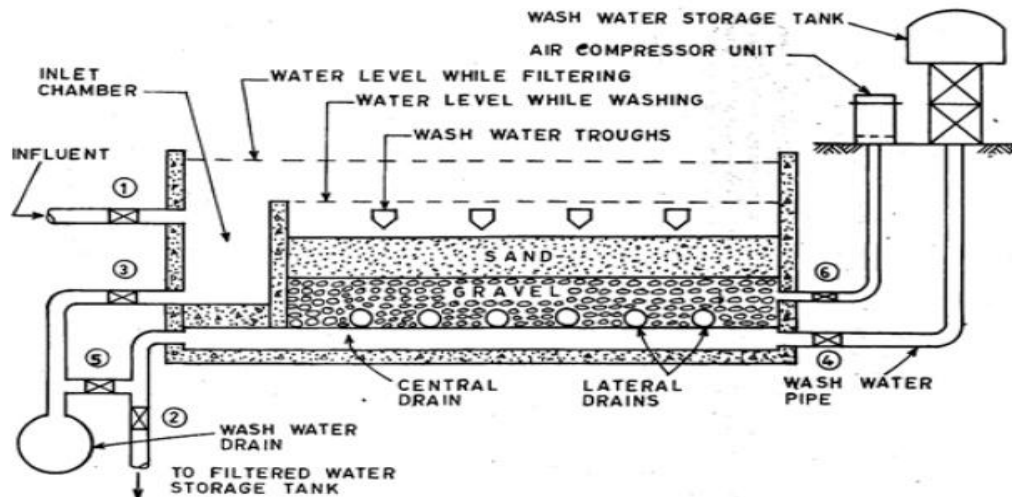
2. Rapid sand filter (RSF)

Fig 6.21 Section of rapid Sand filter (Source: Modi, 1998)

Fig: Rapid Sand Filters

Operational Troubles in Rapid Gravity Filters:

1. **Air Binding:**
   - When the filter is newly commissioned, the loss of head of water percolating through the filter is generally very small. However, the loss of head goes on increasing as more and more impurities get trapped into it.
   - A stage is finally reached when the frictional resistance offered by the filter media exceeds the static head of water above the sand bed. Most of this resistance is offered by the top 10 to 15 cm sand layer. The bottom sand acts like a vacuum, and water is sucked through the filter media rather than getting filtered through it.
   - The negative pressure so developed, tends to release the dissolved air and other gases present in water. The formation of bubbles takes place which stick to the sand grains. This phenomenon is known as Air Binding as the air binds the filter and stops its functioning.

- To avoid such troubles, the filters are cleaned as soon as the head loss exceeds the optimum allowable value.

2. Formation of Mud Balls:

- The mud from the atmosphere usually accumulates on the sand surface to form a dense mat. During inadequate washing this mud may sink down into the sand bed and stick to the sand grains and other arrested impurities, thereby forming mud balls.

3. Cracking of Filters:

- The fine sand contained in the top layers of the filter bed shrinks and causes the development of shrinkage cracks in the sand bed. With the use of filter, the loss of head and, therefore, pressure on the sand bed goes on increasing, which further goes on widening these cracks.

Remedial Measures to Prevent Cracking of Filters and Formation of Mud Balls:

- Breaking the top fine mud layer with rakes and washing off the particles.
- Washing the filter with a solution of caustic soda.
- Removing, cleaning and replacing the damaged filter sand.