2017-2018

Lecture

Seven

Filtration

Environmental Engineering Department

Third Stage

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7.1 Purposes of Filtration:

The purposes of filtration is to remove suspended particles from water by passing the water through a medium such as sand. As the water passes through the filter, floc and impurities get stuck in the sand and the clean water goes through. The filtered water collects in the clear well, where it is disinfected and the sent to the customers.

Filtration is usually the final step in the solid removal process which began with coagulation and advanced through flocculation and sedimentation. in filter, up to 99.5% of the suspended solids in the water can be removed, including minerals, floc, and microorganisms.

7.2 Requirements:

Filtration is now required for most water treatment systems. Filters must reduce turbidity to less than 0.5 NTU in 95% of each month's measurements and the finished water turbidity must never exceed 5 NTU in any sample.

Turbidity alone does not have health implications. Although turbidity is not harmful on its own, turbid water is difficult to disinfect for a variety of reasons. Microorganisms growing on the suspended particles may be hard to kill using disinfection while the particles themselves may chemically react with chlorine, making it difficult to maintain a chlorine residual in the distribution system. Turbidity can also cause deposits in the distribution system that create tastes, odors, and bacterial growths. However, turbid drinking water has other troublesome implications as well. Sand filtration removes some cyst-forming microorganisms, such as *Giardia* which cannot be killed by traditional chlorination. **Cysts** are resistant covers which protect the microorganism while it goes into an inactive state.

Regulations require that at least 99.9% of *Giardia* cysts and 99.99% of viruses be removed from drinking water. Since it is difficult to test directly for these microorganisms, turbidity in water can be used as an indicator for their presence. By requiring a low turbidity in the finished water, treatment plants are ensuring that few or no *Giardia* are present in finished drinking water.

7.3 Location in the Treatment Process:

In the typical treatment process, filtration follows sedimentation (if present) and precedes disinfection. Depending on the presence of flocculation and sedimentation, treatment processes are divided into three groups - conventional filtration, direct filtration, and in-line filtration.

The most common method of filtration is **conventional filtration**, where filtration follows coagulation/flocculation and sedimentation. This type of filtration results in flexible and reliable performance, especially when treating variable or very turbid source water. Some treatment plants operate without some or all of the sediment removal processes which precede filtration. If filtration follows coagulation and flocculation, without sedimentation, it is known as **direct filtration**. This method can be used when raw water has low turbidity. Another type of filtration, known as **in-line filtration**, involves operating the filters without flocculation or sedimentation. A coagulant chemical is added to the water just before filtration and coagulation occurs in the filter. In-line filtration is often used with pressure filters, but is not as efficient with variable turbidity and bacteria levels as conventional filtration is.

7.4 Mechanisms of Filtration:

The filter used in the filtration process can be compared to a sieve or microstrainer that traps suspended material between the grains of filter media. However, since most suspended particles can easily pass through the spaces between the grains of the filter media, ***straining*** is the least important process in filtration. Filtration primarily depends on a combination of complex physical and chemical mechanisms, the most important being ***adsorption***. Adsorption is the process of particles sticking onto the surface of the individual filter grains or onto the previously deposited materials. The forces that attract and hold the particles to the grains are the same as those that work in coagulation and flocculation. In fact, some coagulation and flocculation may occur in the filter bed, especially if coagulation and flocculation of the water before filtration was not properly controlled. Incomplete coagulation can cause serious problems in filter operation.

The third mechanism of filtration is biological action, which involves any sort of breakdown of the particles in water by biological processes. This may involve decomposition of organic particles by algae, plankton, diatoms, and bacteria or it may involve microorganisms eating each other. Although biological action is an important part of filtration **in slow sand filters**, in most other filters the water passes through the filter too quickly for much biological action to occur.

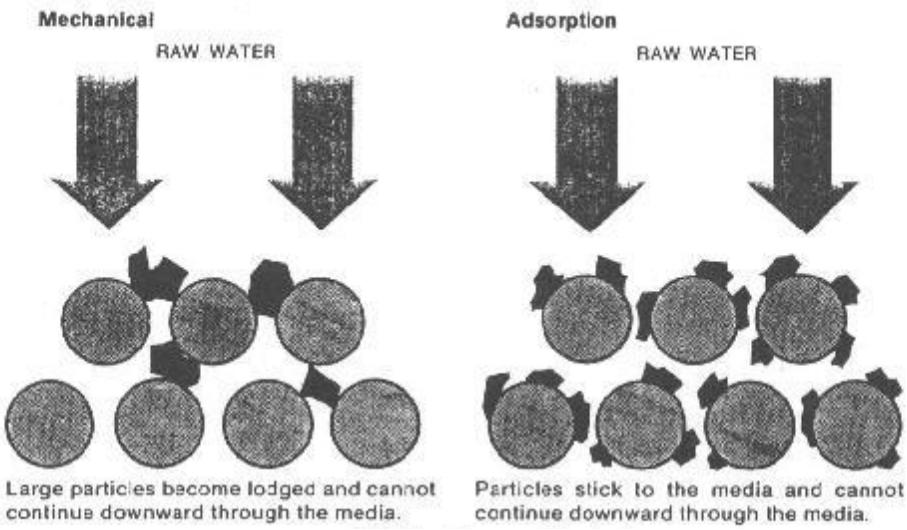


Figure 7.1 : The two removal mechanisms.

7.5 Classification of filters:

1) According to type of granular medium used:

- **Single medium (sand or anthracite)**
- **Dual media (anthracite and sand)**
- M**ulti-media (anthracite, sand, garnet**)

Dual media filters: better longer filtration run . Available pore volume is maximum at the top of filter and gradually decreases to a minimum at the bottom of filter.

2) According to flow through medium

- **Gravity filters:** are open to the atmosphere. Flow through the medium is achieved by gravity
- **Pressure filters:** Filter medium is contained in pressure vessel. Water is delivered to the vessel under pressure

3) According to rate of filtration

- **Rapid sand filters**
- **Slow sand filters**

4) According to filter flow control scheme

- **Constant rate** (constant head or variable head).
- **Declining rate** (constant head or variable head).

The table below shows the characteristics of four types of filters which can be used in water treatment.

Table (7.1): Types of filters.

Type of filter	**Slow Sand Filter (SSF)**	**Rapid Sand Filter (RSF)**	**Pressure Filter**	**Diatomaceous earth filter (Diatomite filter)**
Filtration rate (gpm/ft^2)	0.015-0.15	2-3	2-3	1-2
Pros	Reliable. Mini mum operation and maintenance requirements. Usually does not require chemical pretreatment.	Relatively small and compact.	Lower installation and operation costs in small filtration plants.	Small size. Efficiency. Ease of operation. Relatively low cost. Produces high clarity water. Usually does not require chemical pretreatment.
Cons	Large land area required. Nee d to manually clean filters.	Requires chemical pretreatment. Do esn't remove pathogens as well as slow sand filters.	Less reliable than gravity filters. Filter bed cannot be observed during operation.	Sludge disposal problems. High head loss. Potential decreased reliability. High maintenance and repair costs.
Filter Media	Sand.	Sand. Or sand and anthracite coal. Or sand and anthracite coal and garnet.	Sand. Or sand and anthracite coal. Or sand and anthracite coal and garnet.	Diatomaceous earth. Diatomaceous earth consists of fossilized remains of diatoms, a type of hard-shelled algae.
Gravity or Pressure?	Gravity.	Gravity.	Pressure.	Pressure, gravity, or vacuum.
Filtration Mechanism	Biological action, straining, and adsorption.	Primarily adsorption. Also some straining.	Primarily adsorption. Also some straining.	Primarily straining.
Cleaning Method	Manually removing the top 2 inches of sand.	Backwashing.	Backwashing .	Backwashing.
Common Applications	Small groundwater systems.	Most commonly used type of filter for surface water treatment.	Iron and manganese removal in small groundwater systems.	Beverage and food industries and swimming pools. Smaller systems.

7.5.1 History:

The history of water treatment dates back to approximately the thirteenth century B.C. in Egypt. However, modern filtration began much later. John Gibb's **slow sand filter**, built in 1804 in Scotland, was the first filter used for treating potable water in large quantities. Slow sand filters spread rapidly, with the first one in the United States built in Richmond, in 1832. A set of slow sand filters adapted from English designs was built in 1870 in Poughkeepsie, and is still in operation. A few decades after the first slow sand filters were built in the U.S., the first rapid sand filters were installed. The advent of **rapid sand filtration** is linked to the discovery of coagulation. By adding certain chemicals (coagulants) to turbid water, the material in the water could be made to clump together and quickly settle out. Using coagulation, clear water for filtration could be produced from turbid, polluted streams. By the end of the nineteenth century, there were ten times as many rapid sand filters in service as the slow sand type. Currently, slow sand filtration is only considered economical in unusual cases. **The diatomaceous earth filter** was developed by the U.S. Army during WWII. They needed a filter that was easily transportable, lightweight, and able to produce pure drinking water. The diatomaceous earth filter is used in smaller systems, but is not commonly part of water treatment plants.

We will discuss two types of filters below - the slow sand filter and the rapid sand filter. The pressure sand filter is essentially a rapid sand filter placed inside a pressurized chamber while the diatomaceous earth filter is not commonly used in treatment of drinking water.

7.5.2 Slow Sand Filter:

The slow sand filter is the oldest type of large-scale filter. In the slow sand filter, water passes first through about 36 inches of sand (91.4 cm), then through a layer of gravel, before entering the underdrain. The sand removes particles from the water through adsorption and straining. Typical slow sand filtration velocities are only about 0.04-0.4m/hr.

Unlike other filters, slow sand filters also remove a great deal of turbidity from water using biological action. A layer of dirt, debris, and microorganisms builds up on the top of the sand. This layer is known as **schmutzdecke**, which is German for "dirty skin." The schmutzdecke breaks down organic particles in the water biologically, and is also very effective in straining out even very small inorganic particles from water.

Maintenance of a slow sand filter consists of raking the sand periodically and cleaning the filter by removing the top two inches of sand from the filter surface. After a few cleanings, new sand must be added to replace the removed sand.

Cleaning the filter removes the schmutzdecke layer, without which the filter does not produce potable water. After a cleaning, the filter must be operated for two weeks, with the filtered water sent to waste, to allow the schmutzdecke layer to rebuild. As a result, a treatment plant must have two slow sand filters for continuous operation. Slow sand filters are very reliable filters which do not usually require coagulation/flocculation before filtration. However, water passes through the slow sand filter very slowly, and the rate is slowed yet further by the schmutzdecke layer. As a result, large land areas must be devoted to filters when slow sand filters are part of a treatment plant. Only a few slow sand filters are operating in the United States although this type of filter is more widely used in Europe.

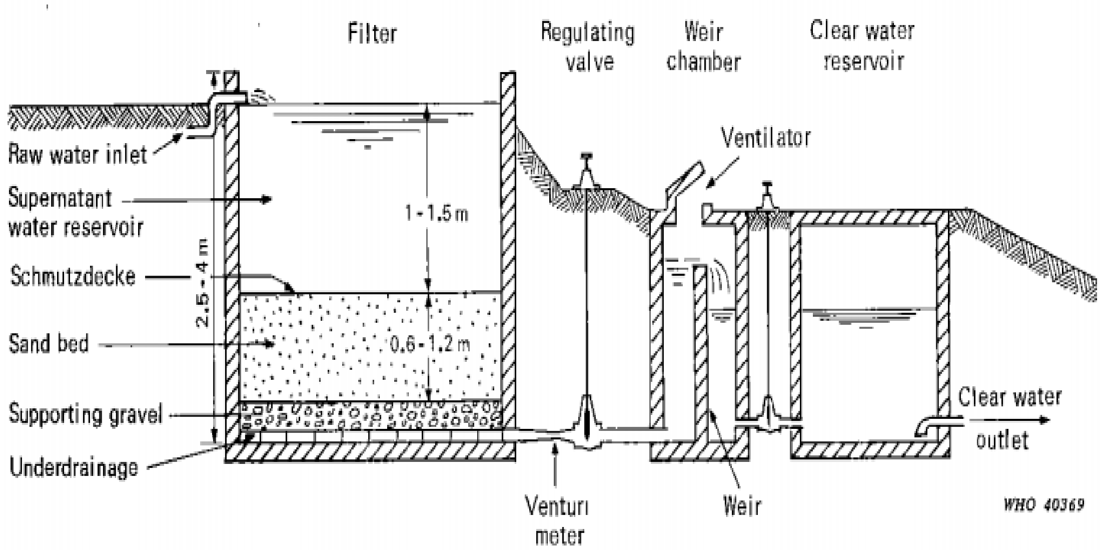


Figure (7.2): Diagram of slow sand filter.

7.5.3 Rapid Sand Filter:

The rapid sand filter differs from the slow sand filter in a variety of ways, the most important of which are the much greater filtration rate and the ability to clean automatically using backwashing. The mechanism of particle removal also differs in the two types of filters - rapid sand filters do not use biological filtration and depend primarily on adsorption and some straining.

Since rapid sand filters are the primary filtration type used in water treatment , we will discuss this filter in more detail. Typical rapid sand filtration velocities are only about 0.4-3.1 m/hr.

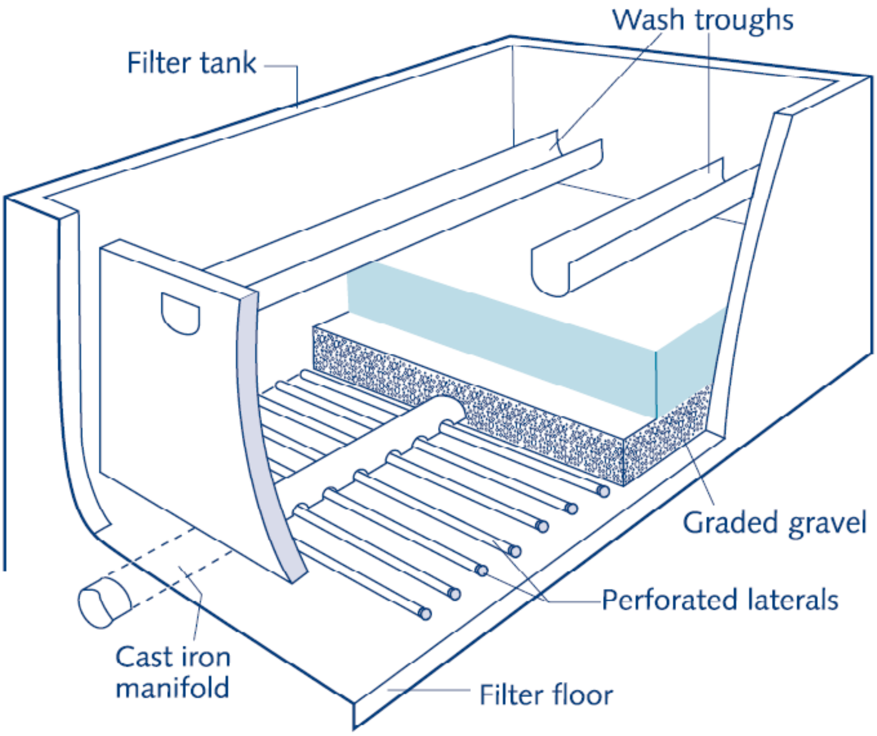


Figure (7.3): Rapid filter

A diagram of a typical rapid sand filter is shown above (Fig. 7.3). The filter is contained within a **filter box**, usually made of concrete. Inside the filter box are layers of **filter media** (sand, anthracite, etc.) and gravel. Below the gravel, a network of pipes makes up the **underdrain** which collects the filtered water and evenly distributes the backwash water. **Backwash troughs** help distribute the influent water and are also used in backwashing (which will be discussed in a later section.). In addition to the parts mentioned above, most rapid sand filters contain a **controller**, or **filter control system**, which regulates flow rates of water through the filter. Other parts, such as valves, a loss of head gauge, surface washers, and a backwash pump, are used while cleaning the filter.

7.6 Filter media:

Filter media commonly are specified by effective size and uniformity coefficient. The effective size (d_{10}) is the size of the standard sieve opening that will pass ten percent by weight of the media. The uniformity coefficient (d_{60}/d_{10}) is the ratio of the standard sieve opening that will pass sixty percent by weight of the media to its effective size. Graphical representation of a standard sieve analysis and determination of d_{10},d_{60} and uniform coefficient are illustrated in Fig (7.4).

7.6.1 Single medium filters:

Single medium filters utilize a single material, most commonly well grad sand. Typical effective size, uniformity coefficient and bed depths for these filters are listed in Table (7.2). In these filters, after backwashing larger grains settle faster than smaller grains, in a phenomena called stratification or reverse gradation. This phenomena is shown in Fig. (7.5). Reverse gradation is the major advantages of the single medium filters. The smaller the top of the filter trap most of the particles, therefore only the top 4 or 5 cm of the filter bed is utilized for filtration. Particles that pass through this Additionally, because only the top 4 to 5 cm of the bed are used, the solids holding capacity of the bed is small, and so filter runs are shortened.

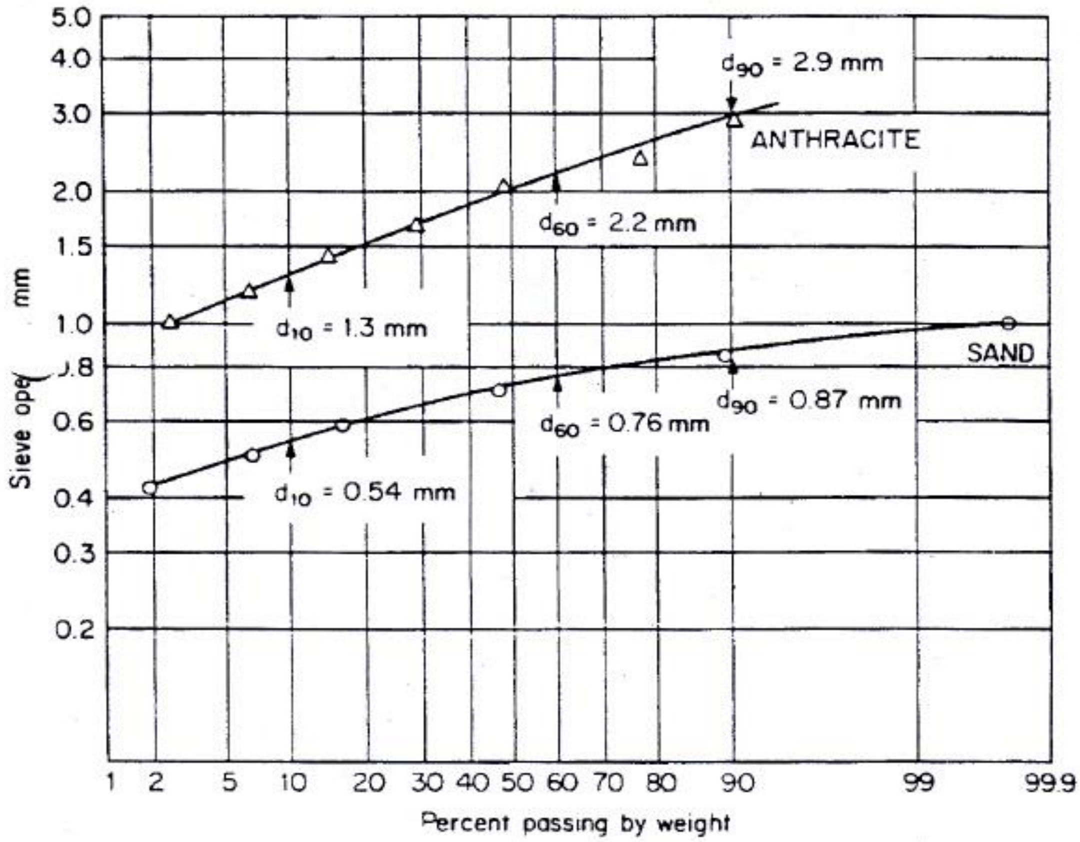


Figure (7.4): Typical sieve analysis of two filter media.

7.6.2 Dual medium filters:

Another solution to the problem of reverse gradation is the dual media filter. Typical dual media filters utilize anthracite coal and quartiz sand as filter media. The anthracite with specific gravity of 1.55 is lighter than the sand which has a specific gravity of 2.65. Therefore, a larger anthracite grain has the same settling velocity as a much as smaller sand grain. This characteristics allows coal grain to be placed on top of smaller sand grains to create a gradation as shown in fig. (7.5). Typical design values for dual media filters are listed in Table (7.2). It can be used a mixed media filters in which we can use garnet (SG=4) in additional to sand and anthracite.

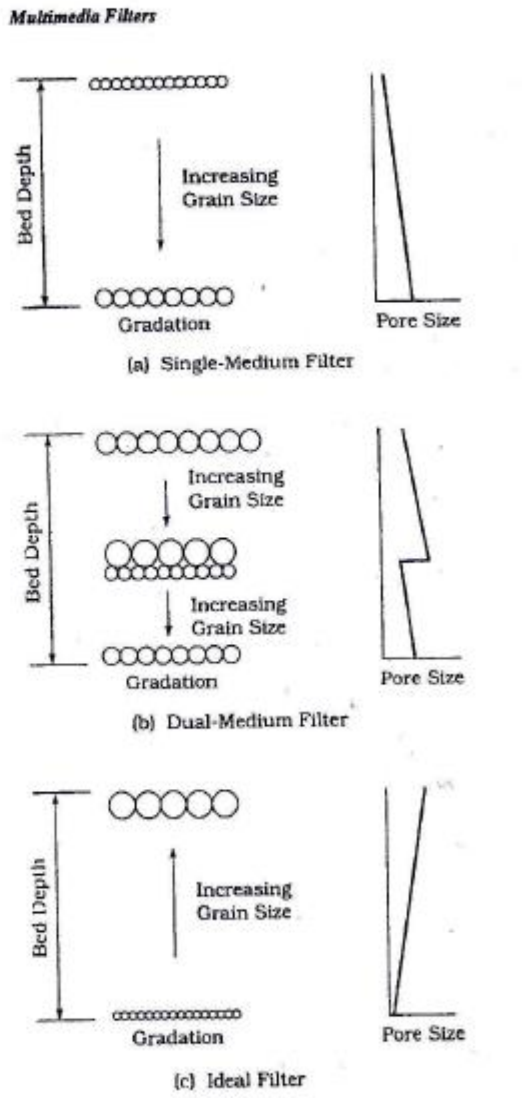


Figure (7.5): Gradation and pore size in various filters.

Table (7.2) : Typical media design values for various filters.

Parameters	***Single media filters***	***Dual media filters***	***Multi media filters***
Anthracite layer			
Effective size, mm	0.5-1.5	0.7-2	1-2
Uniformity coefficient	1.2-1.7	1.3-1.8	1.4-1.8
Depth, cm	50-150	30-60	50-130
Sand layer			
Effective size, mm	0.45-1	0.45-0.6	0.4-0.8
Uniformity coefficient	1.2-1.7	1.2-1.7	1.2-1.7
Depth, cm	50-150	20-40	20-40
Garnet			
Effective size, mm			0.2-0.8
Uniformity coefficient			1.5-1.8
Depth, cm			5-15

The following equation can be used to calculate the size of the media grains with different specific density and equal settling velocity:-

$d_1/d_2 = [Sg_2 - 1/Sg_1-1]^{2/3}$

Example:-

Find the particle size of anthracite and ilmenite which have settling velocities equal to that sand 0.5 mm in diameter.

$S.g_{sand} = 2.6$, $S.g_{anth.} = 1.55$, $S.g_{il} = 4.2$

Solution:-

For anthracite $d_1/0.5= [2.6-1/1.5-1]^{2/3}= 1.1$ mm

For the ilmenite:

$$\frac{d_1}{0.5} = \left\{\frac{2.6-1}{4.2-1}\right\}^{2/3} = 0.3mm$$

0.5 1.1 0.3 at the same settling velocity

Anthracite smaller than 1.1 mm would remain above 0.5 mm sand, and grains of ilmenite larger than 0.3 mm would remain below it.

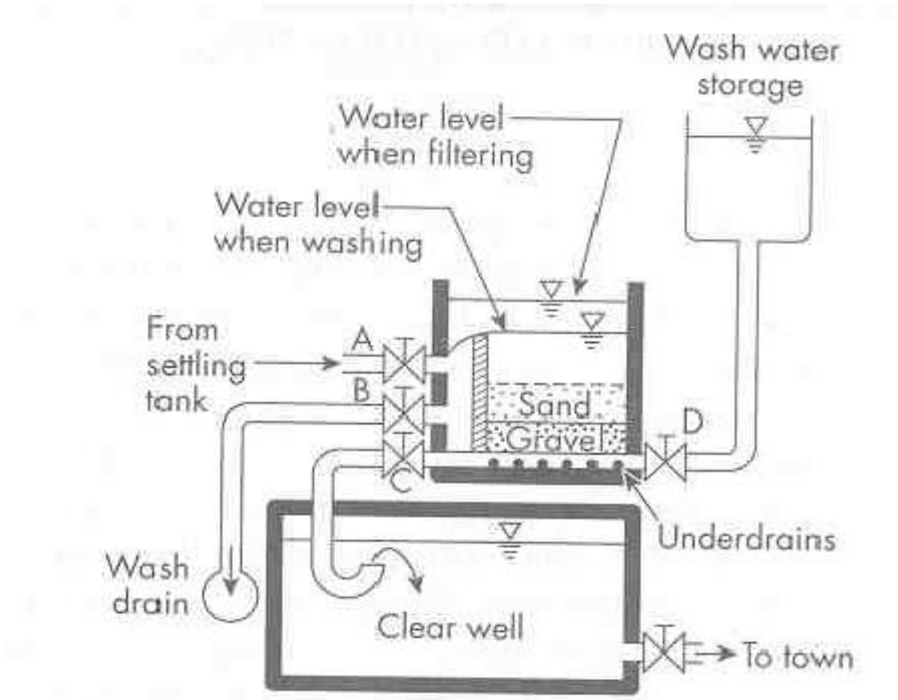
7.7 Filter components:

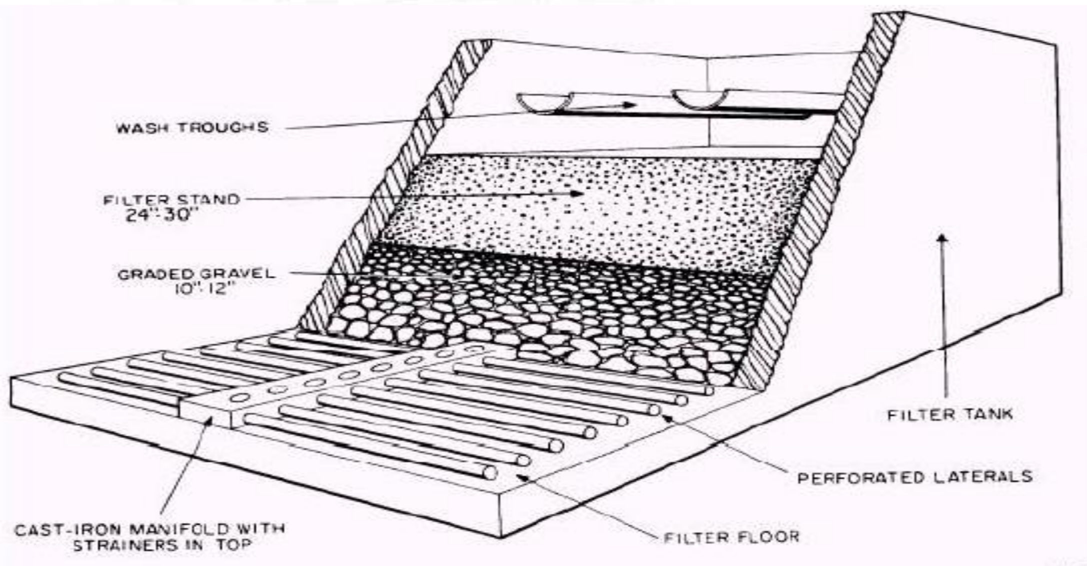
Filter components are shown in Fig. (7.6). They are:

1) Influent pipe 2) Effluent pipe 3) Wash water pipe 4) Filter box

5) Filter media 6) Gravel support 7) Underdrain system 8) Washwater trough.

The influent pipe transports the water from sedimentation tank to the filter. Effluent pipe transports the filtered water to the next step of the water treatment. Washwater pipe transports clean water to the bottom of the filter for the backwash process.





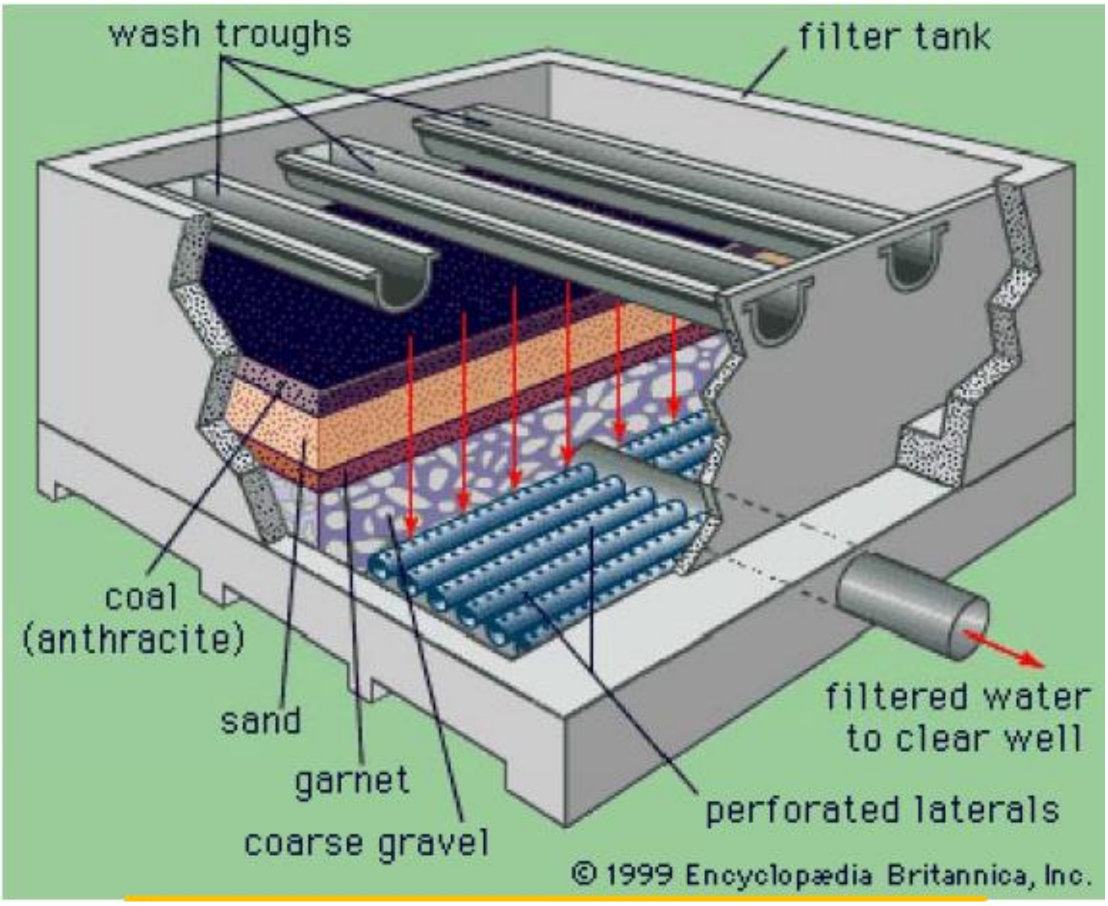


Figure 7.6: Rapid sand filter components

7.7.1 Filter box:

The filter tank is generally constructed from concrete and is most often rectangular. Filters in large plants are usually constructed next to each other in a row, allowing the piping from the sedimentation basins to feed the filters from a central pipe gallery or from a inlet channel. The sizes of filters vary according to the quantity to be treated. The number of filters is selected to minimize the effect of removing the filter from service washing on remaining filters. Filter bed sizes vary from 25 to 100 m^2 with length in the range of 2.5 to 8 m and length to breadth ratio of 1,25 to 1.33.

7.7.2 Underdrain system:

The underdrain serves to support the filter medium and gravel, to collect filtered water evenly from the bottom of the filter, and to distribute air and water evenly across the bottom of the filter during backwashing. Key to these functions is the evenness of filtration and the distribution of backwash air and water. The underdrain system can be one of the following types, connected to main drain: pipe laterals, Concrete block, False floor and porous plates or strainer nozzles.

One common type of uderdrain consist of a manifold and perforated laterals installed below the gravel bed. Most new designs using a plastic piping system for filter underdrains. Piping materials must be certified for contact with potable water. Typical lateral size ranging from 4 to 8 inch (100 – 200 mm) with the underdrain system header in the range of 8 to 16 inch (200 to 400 mm).

Table 7.3 gives the typical design parameters of an underdrain system (lateral manifold system) for a small rapid sand filter. Typical arrangements of perforated pipe under drains are shown in Fig. (7.7). Figure (7.8) is a view of an installation in progress of perforated PVC underdrain system.

Table 7.3: Design Criteria for Underdrains

Criterion	Value
Minimum diameter of underdrains	20 cm
Diameter of the perforations vertical	6-12 mm (suggested at a slight angle to the axis of the pipe)
Spacing of perforations along laterals	7.5 cm for 6 mm perforations
Ratio of total area of perforation to total cross-sectional area of laterals	0.25 for 6 mm perforations 0.50 for 12 mm perforations
Ratio of total area of perforations to the entire filter area	0.003
Length to diameter ratio of the lateral	60:1
Maximum spacing of lateral	30 cm
Cross-sectional area of the manifold	1.5-2.0 times the total area of laterals
Velocity of the filtered water outlet	1.0-1.8 m/s

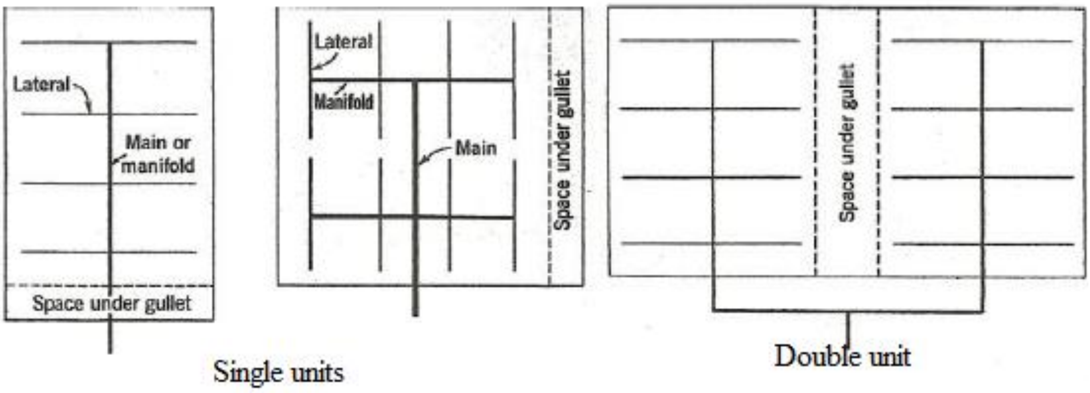


Figure (7.7): Perforated Pipe Underdrains

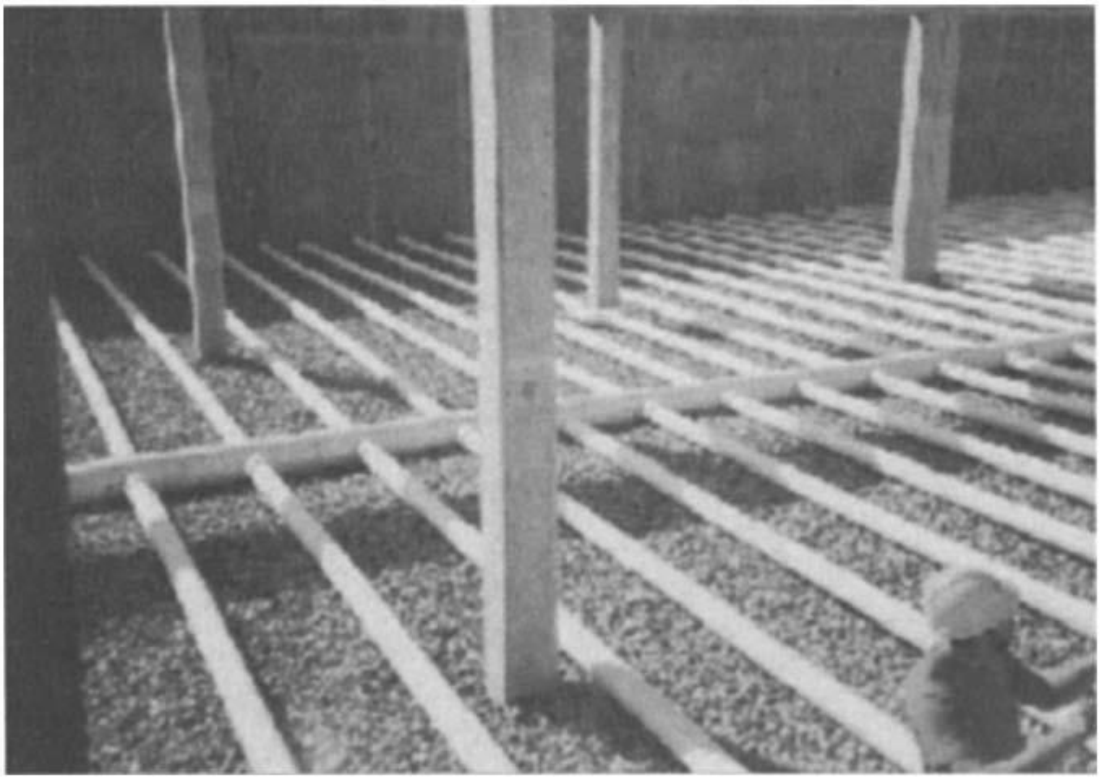


Figure (7.8): Underdrain installation

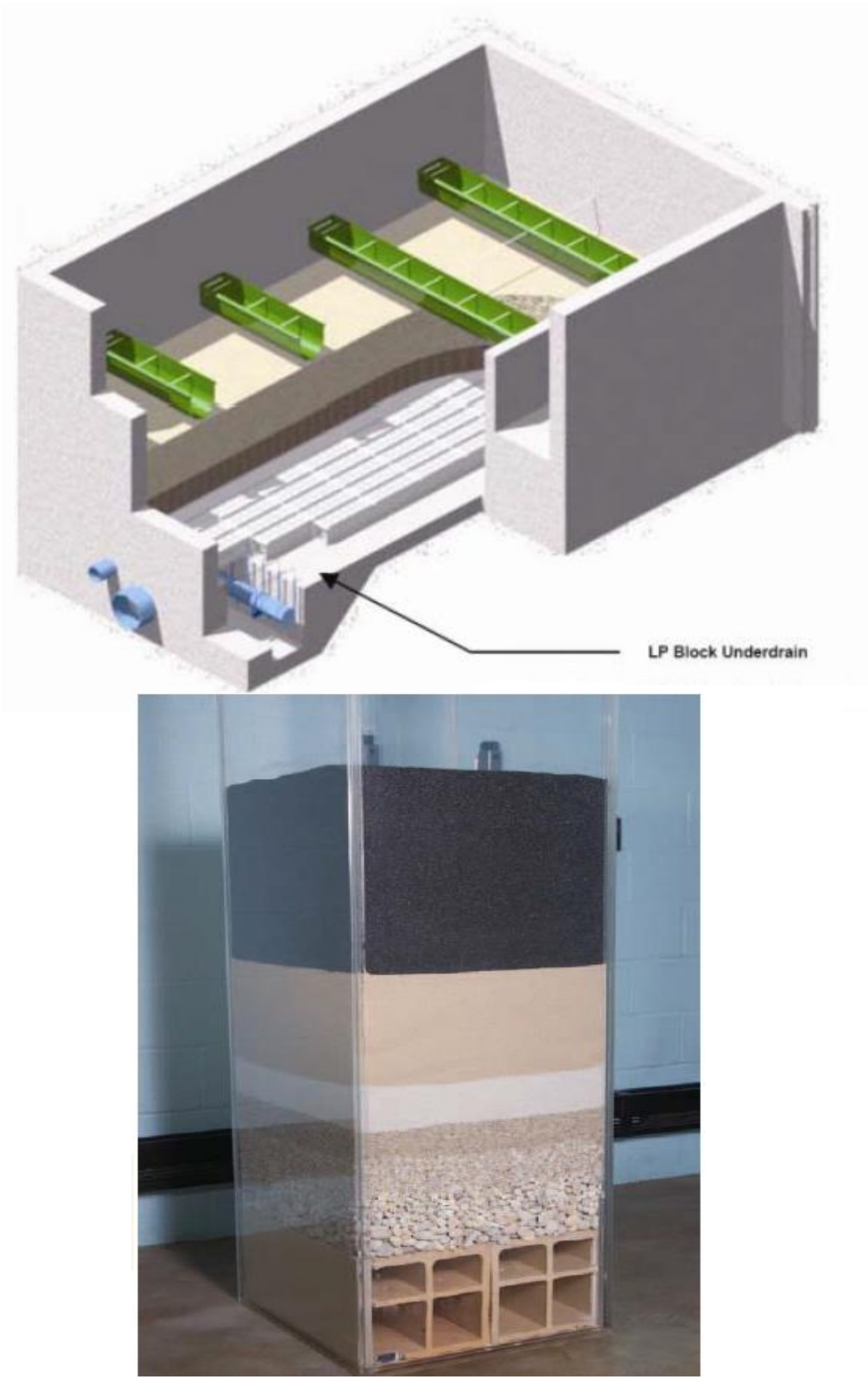
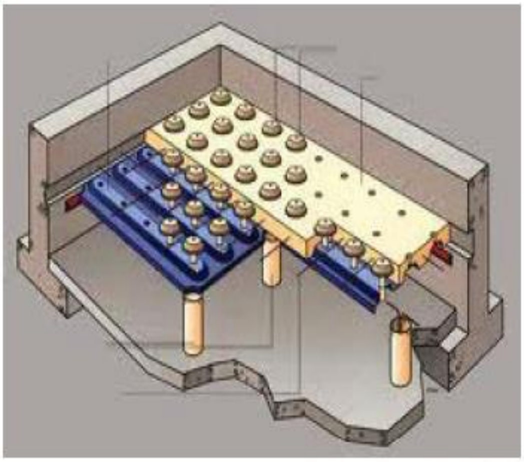
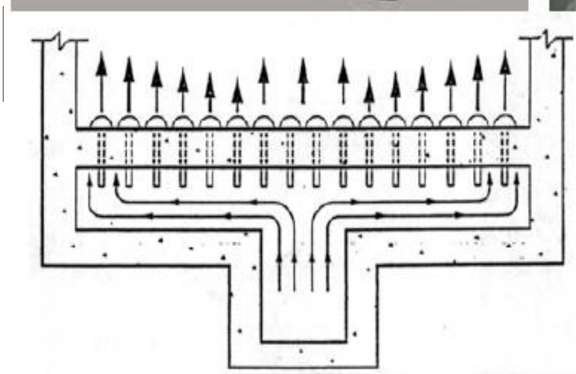
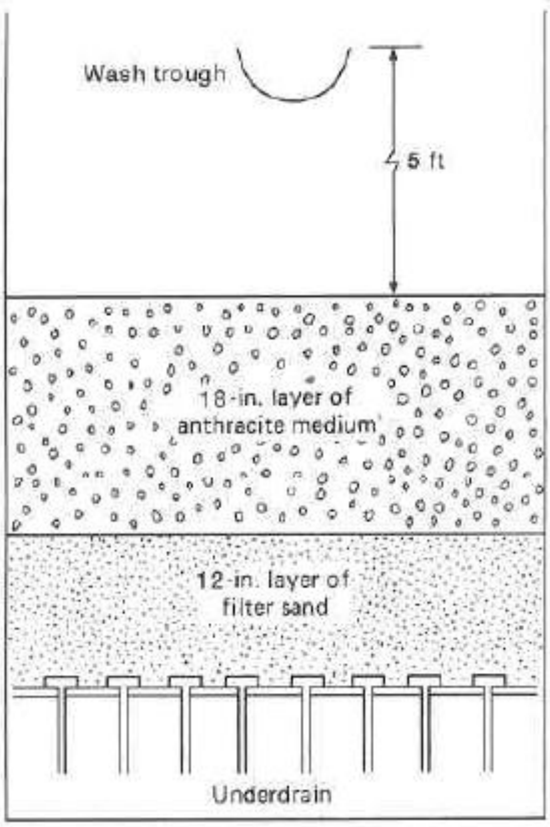


Figure (7.9): Rapid sand filter components: with ducts under- drain system







(a)

Figure (7.10): Rapid sand filter perforated slab and nozzle under-drain

7.7.3 Washwater troughs:

Washwater troughs placed above the filter media collect the backwash water and carry it to the drain system. The bottom of the trough should be above the top of the expanded sand to prevent possible loss of sand during backwashing. The clear horizontal distance between troughs is usually 5 to 7 ft (1.5- 2 m). The trough usually has a semicircle bottom. Troughs may be made of concrete, fiberglass-reinforced plastic, or other structurally adequate and corrosion resistant materials. The dimensions of a filter trough may be determined by use of the following equation:

$Q = 2.49\ bh^{3/2}$

Where Q = rate of discharge, ft^3/sec

b = width of trough, ft.

h = maximum water depth in trough, ft.

Some free board should be allowed in the wash water troughs.

The use of the above formula is illustrated in the following example:

Example:

Rectangular troughs 24 ft long, 18 in wide and 7 ft on centers are to serve a filter that is washed at a rate of 30 in. per minute. Determine: (a) the depth of the troughs if their invert is to be kept level and they are to discharge freely into the gutter, and (b) the height of the top of the trough above the sand if a 30-in. bed is to be expanded by 50 percent.

Solution:

Rate of discharge Q = 24x7x[30/(12x60)]

= 7 ft3/sec

b = 18/12 = 1.5 ft

Applying the above data in Equation,

$7 = 2.49x1.5xh^{3/2}$

$h^{3/2} = 7/(2.49x1.5)$

$h = [7/(2.49x1.5)]^{2/3}$

= 1.52 ft………………….(a)

Expansion of sand = 0.5x30 = 0.5x(30/12) =1.25 ft

Height of trough top above sand = 1.52 + 1.25

= 2.77 ft plus some free board………….(b)

Typical arrangement of wash water troughs is shown in Fig. (7.11) below.

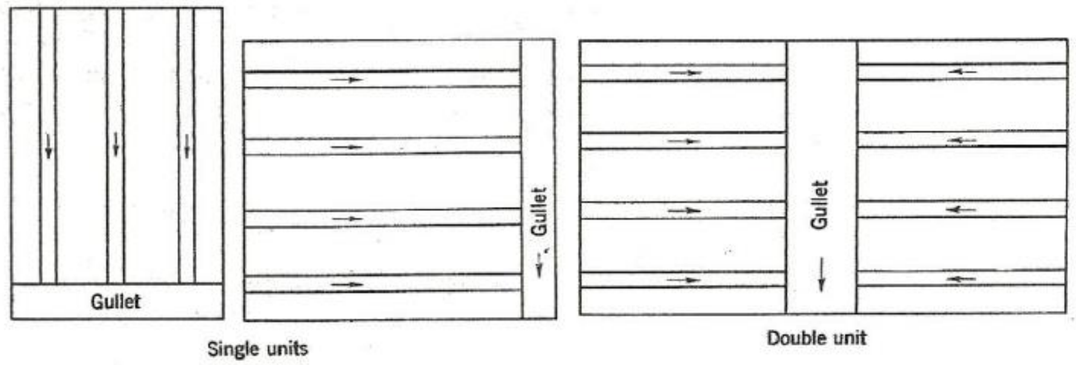


Figure (7.11): Typical arrangement of wash water troughs.

7.8 Filter Cleaning:

7.8.1 When to Backwash:

Rapid sand filters, pressure filters, and diatomaceous earth filters can all be backwashed. During **backwashing**, the flow of water through the filter is reversed, cleaning out trapped particles.

Three factors can be used to assess when a filter needs backwashing. Some plants use the length of the **filter run**, arbitrarily scheduling backwashing after 72 hours or some other length of filter operation. Other plants monitor **turbidity of the effluent** water and **head loss** within the filter to determine when the filter is clogged enough to need cleaning.

Head loss is a loss of pressure (also known as head) by water flowing through the filter. When water flows through a clogged filter, friction causes the water to lose energy, so that the water leaving the filter is under less pressure than the water entering the filter. Head loss is displayed on a head loss gauge. Once the head loss within the filter has reached between six and ten hours (1.5-2.5 m) , a filter should be backwashed.

7.8.2 The Process of Backwashing:

The first operation is to close valves 1 and 4 (Fig. 12) and allow the filter to drain until the water lies a few centimeters above the top of the bed. The valve 5 is opened, and air is blown back through a compressed air unit at a rate of about 1-1.5 m^3 free air/min.m^2 of bed area for about 2-3 minutes at a pressure of 20-35 kN/m^2. The water over the bed quickly becomes very dirty as the air-agitated sand breaks up surface dirt. Following this, valves 2 and 6 are opened, and an upward flow of water is sent through the bed at a carefully designed high velocity. This should be sufficient to expand the bed (20-50%) and cause the sand grain to be agitated so that deposits are washed off them, but not so high that the sand grains are carried away in the rising upward flush of water. After the washing of the filters has been completed, valves 2 and 6 will be closed, and valves 1 and 3 opened. This restores the inlet supplied through valve 1. The filtered water is wasted to the gutter for a few minutes after this, until the required quality is achieved. Ultimately, valve 3 is closed and 4 is opened to get the filtered water a gain. The entire process of backwashing the filters and restarting the supplies takes about 15 minutes. The specified minimum backwash time for a rapid filters is 5 minutes, The amount of water required to wash a rapid filter may vary from 3-6% of the total amount of water filtered. Upward wash rates are usually of the order of 0.3-1.0 m/min.

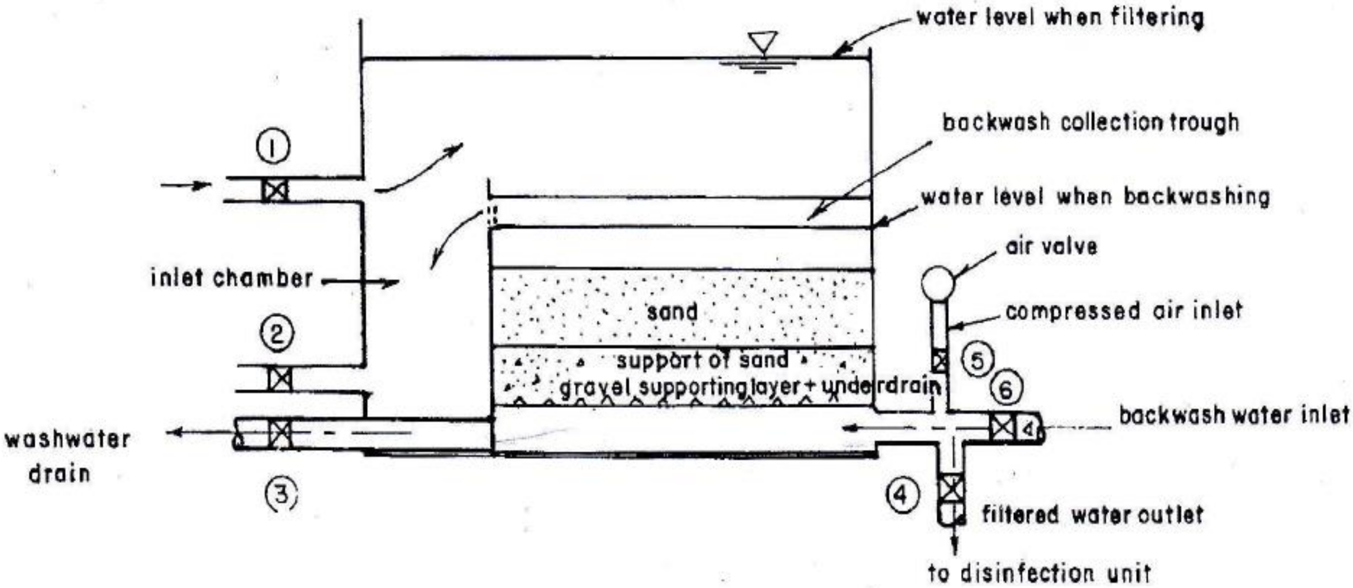


Figure (7.12): Diagrammatic section of rapid sand filter.

The design of wash water troughs is similar to that in the pervious lecture. The back wash velocity for the sand and anthracite are calculated from the following equations:

$U_b = d_{60}$ (for sand)

$U_b = 0.47d_{60}$ (for anthracite)

Where U_b is the backwash velocity, m/min. The terminal settling velocity for the sand and anthracite is calculated from:

$U_t = 10d_{60} = 10d_{10}$* uniformity coefficient (for sand).

$U_{t=}$ 4.7d60=$4.7d_{10}$* uniformity coefficient (for anthracite).

If the porosity of the sand or anthracite is specified, the :

$U_b = U_t \times f^{0.45}$

7.8.3 Surface Washing:

At the same time as backwashing is occurring, the surface of the filter should be additionally scoured using **surface washers**. Surface washers spray water over the sand at the top of the filter breaking down mud balls.

7.9 Estimation of head losses:

7.9.1 Clean water head loss:

Several equations have been developed to describe the flow of clean water through a porous medium. Carmen-Kozeny equation used to calculate head loss is as follow :

$$h_L = f\frac{(1-\alpha)LV_s^2}{\phi\alpha^3 dg}$$

$$f = 150\frac{(1-\alpha)}{R_n} + 1.75$$

$$R_n = \frac{\phi d V_s \rho}{\mu}$$

Where, h= head loss, m

f= friction factor

α= porosity

ϕ= particle shape factor (1.0 for spheres, 0.82 for rounded sand, 0.75 for average sand, 0.73 for crushed coal and angular sand).

L= depth of filter bed or layer, m

d= grain size diameter, m

V_s= superficial (approach) filtration velocity, m/s.

g= acceleration due to gravity, 9.81 m^2/s.

d_g=geometric mean diameter between sieve sizes, d_1 and d_2.

R_n= Reynolds number

μ=viscosity, N.s/m.

7.9.2 Back wash water head loss:

The head loss through back wash is the summation of the heads loss in the expanded bed, the gravel, the underdrains, the pipe, and valves.

$H=h_f+h_g+h_u+h_p$

h_f is the head loss in the expanded bed:

$h_f=L(1-\alpha)(S_g-1)$

where L is the depth of unexpanded bed, S_g is the specific density of the medium.

h_g is the head loss in the gravel:

$$h_g = 200L_g \frac{U_b \mu}{\rho g \phi^2 d_{60}^2} \times \frac{(1-\alpha)}{\alpha^3}$$

where L_g is the depth of the gravel.

Hu is the head loss in the underdrain system:

$$h_u = \frac{1}{2g}\left(\frac{U_b}{\gamma \beta}\right)^2$$

Where γ is an orifice coefficient and β is the ratio of the orifice area to the filter bed area (normally 0.2 to 0.7 percent).

h_p is the head loss in the pipe and valves. If these are replaced by an equivalent pipe the head loss is calculate from:

$$h_p = F\frac{L}{d}\left(\frac{4AU_b}{\pi d^2}\right)^2$$

where L is the depth, d is the diameter and F is the friction factor of the equivalent pipe and A is the filter bed area.

7. 10 Design of rapid sand filter:

We will design a rapid sand filter and a clear well chamber. For the rapid sand filter, the most important dimension is the surface area. Filters must be designed so that the water flowing through is spread out over enough surface area that the filtration rate is within the recommended range.

The **clear well** is a reservoir for storage of filter effluent water. In this lesson, we will design a clear well with sufficient volume to backwash the rapid sand filter we design. However, clear wells have other purposes, most important of which is to allow sufficient contact time for chlorination. We will discuss chlorination in the next lesson.

Example:

A water treatment plant will typically have several filters. Each filter in our calculations will be assumed to have the following specifications.

- Square tank
- Basin depth: 10 ft
- Media depth: 2-3 ft
- Surface area: <2,100 ft^2
- Filtration rate: 2-10 gal/min-ft^2
- Flow through filter: 350-3,500 gpm
- Backwash frequency: every 24 hours
- Backwash period: 5-10 minutes
- Backwash water: 1-5% of filtered water
- Backwash rate: 8-20 gal/min-ft^2
- Filter rise rate: 12-36 in/min
- Bed expansion: 50%
- Backwash trough 3 ft above media
- Backwash water piped to raw water intake

As you can see, backwashing is a very important part of filter calculations. We will briefly identify some of the backwash characteristics below.

The **backwash frequency** is the same as filter run time. Either term can be used to signify the number of hours between backwashing.

The **backwash period** is the length of time which backwashing lasts.

The **backwash water** is the water used to backwash the filter. For the filters we're considering, backwash water should be 1-5% of the water filtered during the filter run.

The **backwash rate** is the rate at which water is forced backwards through the filter during backwashing. This rate is homologous to the filtration rate, only with water moving in the other direction through the filter. The backwash rate is typically much greater than the filtration rate.

The **filter rise rate** is the speed at which water rises up through the filter during backwashing. This is another way of measuring the backwash rate.

During backwashing, the water pushes the media up until it is suspended in the water. The height to which the media rises during backwashing is known as the **bed expansion**. For example, if the filter media is 2 feet deep, it may rise up to 3 feet deep during backwashing. This is a 50% bed expansion:

$$\text{Bed expansion} = \frac{(\text{New depth} - \text{Old depth}) \times 100\%}{\text{Old depth}}$$

$$\text{Bed expansion} = \frac{(3\text{ ft} - 2\text{ ft}) \times 100\%}{2\text{ ft}}$$

Bed expansion = 50%

Most of these backwash specifications merely describe the type of filter we will be considering and are not used in calculations. However, two factors - the filter rise rate and the backwash period - will be used when calculating the volume of the clear well chamber.

Overview of Calculations:

1. Calculate the approximate number of filters required.
2. Calculate the flow through one filter.
3. Calculate the surface area of one filter.
4. Calculate the length of the tank.
5. Calculate the clearwell volume.

1. Number of Filters:

The treatment plant's flow should be divided into at least three filters. You can estimate the number of filters required using the following formula:

$$\text{Number of filters} = 2.7\sqrt{Q}$$

Where:

Q = Flow, MGD

So, for a plant with a flow of 1.5 MGD, then the approximate number of filters would be:

$$\text{Number of filters} = 2.7\sqrt{1.5}$$

$$\text{Number of filters} = 3$$

2. Flow:

Next, the flow through one filter is calculated just as it was for one tank of the sedimentation basin:

$Q_{one} = Q_{total} / n$

$Q_{one} = (1.5 \text{ MGD}) / 3$

$Q_c = 0.5$ MGD

So the flow through each of our three filters will be 0.5 MGD.

3. Surface Area:

The required filter surface area is calculated using the formula below:

$A = Q_{one} / F.R.$

Where:

A = filter surface area, ft^2

Q_c = flow into one filter, gpm

F.R. = filtration rate, gal/min-ft^2

We will use a filtration rate of 4 gal/min-ft.^{2} We will also have to convert from gpm to MGD. The calculations for our example are shown below:

$A = 500{,}000 \text{ gal/day} \times (1 \text{ day} / 1440 \text{ minutes}) / 4 \text{ gal/min-ft}^2$

$A = 87 \text{ ft}^2$

4. Tank Length:

Since the filter tank is a square, the length of the tank can be calculated with the following simple formula:

$L = \sqrt{A}$

Where:

L = Length, ft

A = Surface area, ft^2

In the case of our example, the length of one tank is calculated as follows:

$L = \sqrt{87}$

$L = 9.3$ ft

This is the final calculation required for the design of the filter.

5. Clearwell Volume (Tank of backwash):

The volume of the clear-well must be sufficient to provide backwash water for each filter. First we calculate the total filter area:

Total filter area = A × (Number of filters)

For our example, the total filter area is:

Total filter area = 87 ft^2 × 3

Total filter area = 261 ft^2

Then we calculate the volume of the clearwell as follows:

V = (Backwash period) (Total filter area) (Filter rise rate)

We will assume a 5 minute backwash period and filter rise rate of 30 in/min. So, for our example, the volume of the clearwell would be calculated as follows:

V = (5 min) (261 ft^2) (30 in/min) (1 ft / 12 in)

V = 3, 263 ft^3

You will notice that we translated from inches to feet.

So, for our plant, we need three filters, each with a surface area of 87 ft^2 and a length of 9.3 ft. In order to accommodate backwashing all three filters at once, the clearwell volume should be 3,263 $ft.^3$

Example:

Filters of water treatment plant have the following data:

-Total flow is 15000 m^3/day. – Filtration rate is 125 m/day.

- Dimension of one filter is 4 m width and 6 m length.

- Backwash of filter every 42 hrs.-Backwash rate is 14.4 m/hr for 0.2 hr.

-Influent suspended solid concentration to filter is 0.0018%.

Effluent suspended solid concentration out filter is 5% of influent suspended solid concentration.

-Specific gravity of S.S is 1.2 ton/m^3.

-Use two trough for each filter, n=0.013

Find the following: (1) No. of filters required. (2) Volume of voids of filter.

(3) Volume of tank of backwash water of filter. (4) Dimensions of ⊔ shape trough.

Solution:

1- Q= 15000 m^3/day, Filtration rate, F.R= 125 m/day

$$Total\ area = \frac{Q}{F.R} = \frac{15000}{125} = 120\ m^2$$

$$Area\ of\ one\ filter = 4 \times 6 = 24\ m^2$$

$$No.\ of\ filters\ required = \frac{120}{24} = 5\ filters\ (use\ one\ standby)$$

2- Influent S.S= 0.0018%=18 ppm= 18 mg/L
Effluent S.S= 0.05 × Influent S.S= 0.05 × 18= 0.9 mg/L
S.S removed= 18-0.9=17.1 mg/L=17100 mg/m^3
Weight of S.S removed=17100 × 125×(42/24)×(4×6)=0.089775 Ton
Volume of voids of filter= 0.089775/1.2=0.0745 m^3

3- Volume of backwash water (Volume of Clearwell tank)= Area of filter ×backwash rate × time for washing.
=(4×6)×14.4×0.2=69.12 m^3.

4- Assume b=y

$$y = 1.73\left[\frac{Q^2}{gy^2}\right]^{1/3}$$

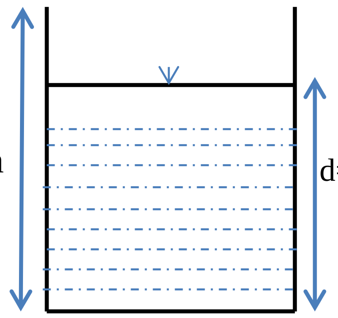
Q backwash= $V_{backwash}$×A of half filter
= 14.4 ×(4×3)= 172.8 m^3/hr= 0.048 m^3/sec

$$y^5 = 1.73^3 \frac{Q^2}{g}$$

$$y^5 = 1.217 \times 10^{-3}$$

$$y = 0.26126\,m$$

$$b = 0.26126\,m$$



$$y_X = y(1 - 0.422\frac{X^2}{L^2})$$

Where y_X is the water depth at any distance, m.

X is the distance, m

y is the trough depth, m.

$$y_X = y(1 - 0.422\frac{X^2}{L^2})$$

$$y_L = y(1 - 0.422\frac{L^2}{L^2})$$

$$y_L = 0.578\,y$$

$$d = \frac{y}{1.73} = \frac{0.26126}{1.73} = 0.15102\,m$$

5- Slop of trough $S = (\frac{nv}{r^{2/3}})^2$

$$r = \frac{A}{P} = \frac{d \times b}{2d + b} = \frac{0.15 \times 0.26}{2 \times 0.15 + 0.26} = 0.0696$$

$$v = \frac{Q}{A} = \frac{Q}{d \times b} = \frac{0.048}{0.15 \times 0.26} = 1.231\,m/s$$

$$S = (\frac{0.013 \times 1.231}{0.0696^{2/3}})^2 = 0.0089\,m/m$$

Total head loss in trough=S× length of trough (width of filter)= 0.0089×4=0.035m

6- Head loss in filter bed

Applied Carmen-Kozney equation:

$$h_f = \frac{fL(1-e)v_s^2}{e^3 g d_p}$$

$$v_s = 125\frac{m}{day} \times \frac{1day}{86400sec} = 0.0014m/sec$$

$$e = \frac{Volume of voids}{volume of filter bed}$$

$$Volume of filter bed = 0.6 \times 4 \times 6 = 14.4m$$

$$e = \frac{0.0745}{14.4} = 0.00517$$

$$h_f = \frac{2.6 \times 10^{-4} \times 0.6(1-0.00517)(0.0014)^2}{0.00517^3 \times 9.81 \times \frac{0.5}{1000}} = 0.224m$$