Sanitary and Environmental Engineering

PART 1: WATER SUPPLY ENGINEERING

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PART 1: WATER SUPPLY ENGINEERING

Lecture 9: Filtration

Filtration is the separation of non-settleable solids from water by passing it through a porous media. Filtration also removes from water: color, taste, odor, iron, manganese and microorganisms such as bacteria. In water treatment plants this is done in a unit known as the filter.

Types of filter according to process workability:

1) Gravity filter:

   a) Slow sand filter: They consist of fine sand, supported by gravel. They capture particles near the surface of the bed and are usually cleaned by scraping away the top layer of sand that contains the particles.
   b) Rapid-sand filter: They consist of larger sand grains supported by gravel and capture particles throughout the bed. They are cleaned by backwashing water through the bed to 'lift out' the particles.

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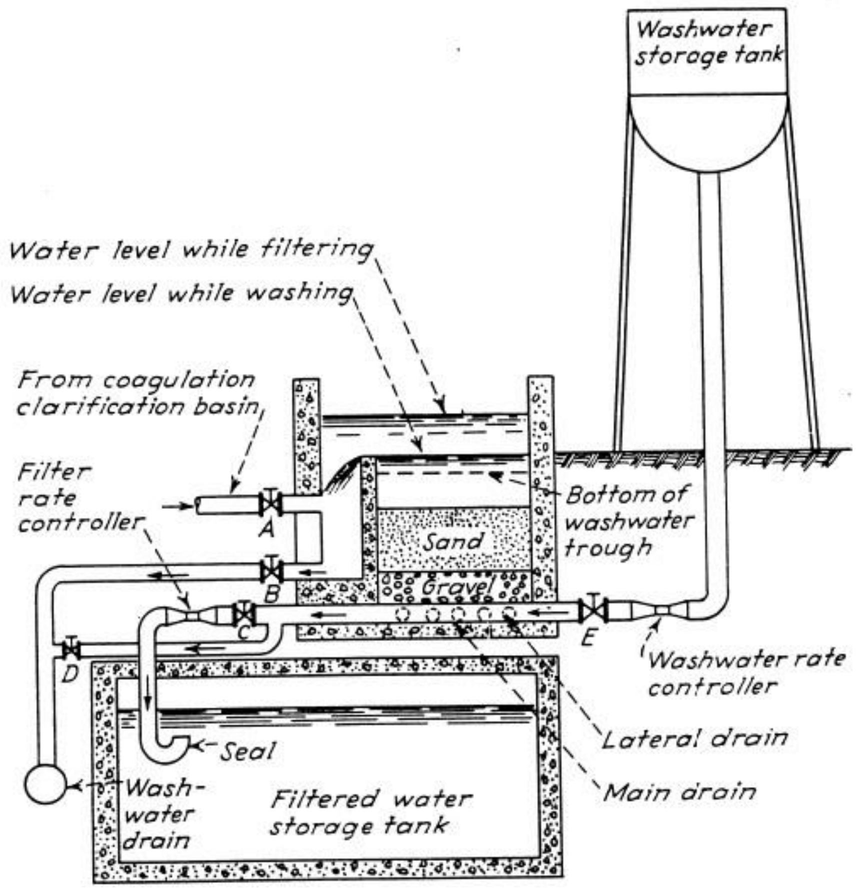

Diagrammatic section of a rapid sand gravity filter.

2) Pressure filter:

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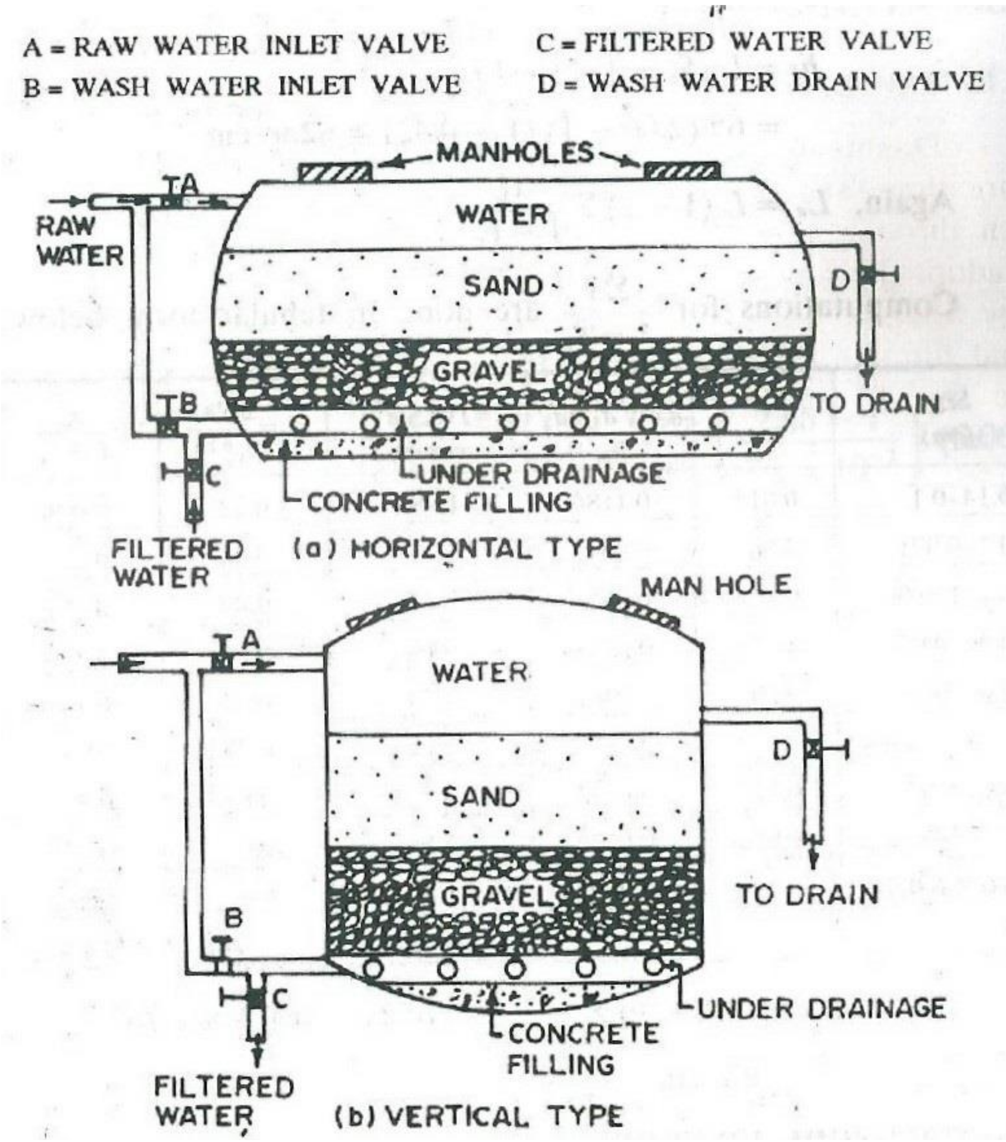

Pressure filter.

Types of filter according to media:

1) Mono-media: as sand or anthracite.
2) Multimedia filters: They consist of two or more layers of different granular materials, with different densities. Usually, anthracite coal, sand, and gravel are used. The different layers combined may provide more versatile collection than a single sand layer. Because of the differences in densities, the layers stay neatly separated, even after backwashing.

Filter Media:

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The choice of a filter medium is dictated by the durability required, the desired degree of purification, and the length of filter run and ease of backwash sought. The ideal medium should have such a size and be of such material that it will provide a satisfactory effluent, return a maximum quantity of solids, and be readily cleaned with a minimum of wash water.

1) **Sand:** Sand, either fine or coarse, is generally used as filter media. The size of the sand is measured and expressed by the term called effective size. The effective size, i.e. D_{10} may be defined as the size of the sieve in mm through which ten percent of the sample of sand by weight will pass. The uniformity in size or degree of variations in sizes of particles is measured and expressed by the term called uniformity coefficient. The uniformity coefficient, i.e. ($D_U = \frac{D_{60}}{D_{10}}$) may be defined as the ratio of the sieve size in mm through which 60 percent of the sample of sand will pass, to the effective size of the sand.

2) **Gravel:** The layers of sand may be supported on gravel, which permits the filtered water to move freely to the underdrains, and allows the wash water to move uniformly upwards.

3) **Other materials:** Instead of using sand, sometimes, anthracite is used as filter media. Anthracite is made from anthracite, which is a type of coal-stone that burns without smoke or flames. It is cheaper and has been able to give a high rate of filtration.

Fine material	Coarse material
1) Better effluent 2) High head loss in upper layers of the bed. 3) Short filter runs. 4) Most difficult in cleaning upon backwash	1) Better utilization of the storage capacity of the filter. 2) Permit deeper penetration of the floc. 3) Longer filter runs. 4) Easier cleaning upon backwash

Sand	Anthracite	Gravel
1) Clean, hard, and resistance. 2) Not lose more than 5% by weight after being placed in 40% hydrochloric acid for 24 hr. 3) Sand depth 600-700 mm. 4) Effective size of 0.45-0.55 mm. 5) Uniformity coefficient not less than 1.2 and not exceed 1.7.	1) Anthracite depth 600-700 mm. 2) Effective size of 0.7 mm. 3) Uniformity coefficient of 1.75 or less.	1) Hard, rounded, durable, free from flat, thin, and contain no foreign material. 2) Effective size between 0.8 to 2 mm. 3) Uniformity coefficient of not over 1.7.

Filtration Mechanisms: There are four basic filtration mechanisms:

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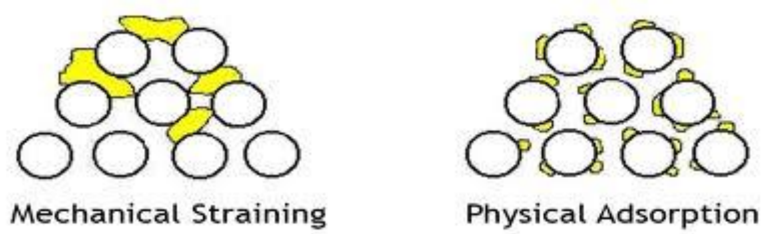
1) **Sedimentation:** The mechanism of sedimentation is due to force of gravity and the associate settling velocity of the particle, which causes it to cross the streamlines and reach the collector.
2) **Interception:** Interception of particles is common for large particles. If a large enough particle follows the streamline that lies very close to the media surface it will hit the media grain and be captured.
3) **Brownian diffusion:** Diffusion towards media granules occurs for very small particles, such as viruses. Particles move randomly about within the fluid, due to thermal gradients. This mechanism is only important for particles with diameters < 1 micron.
4) **Inertia:** Attachment by inertia occurs when larger particles move fast enough to travel off their streamlines and bump into media grains.



The area of filter medium which is a function of particle size and bed depth, it follows that increasing the size of the medium will require an increase in depth.

Rapid Sand Filters (RSF)

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Rapid filtration generally implies a process which includes coagulation, flocculation, clarification, filtration, and disinfection.

Essential characteristics of a rapid filter:

1) The turbidity of water applied to the filters should not exceed 10 units and preferably 5 units,
2) High rate of filtration, 120 to 240 m/day,
3) Washing the filter units by revising flow of filtered water upward through the filter to remove mud and other impurities which have lodged.

Filter component: As shown in the figures above:

A) Water head: Clearance, 600-900 mm in depth.
B) Filer bed (Sand layer), 600- 1200 mm in depth. The objectives of this layer:
   i. Coarse to retain large quantity of solid particles.
   ii. Fine to prevent the passage of small solid particles.
   iii. Deep layer to allow long filtration run.
   iv. Graded to permit good backwash cleaning.
   Properties: Effective size (D_{10})= 0.45 -0.55 mm, Uniformity coefficient (C_u)= D_{60}/D_{10} =1.2-1.7.
C) Gravel layer (bed), 400-600 mm in depth. The objectives of this layer:
   i. Support the filter bed (sand layer).
   ii. Permit the filtered water to move freely towards the underdrain system.
   iii. Allows the washing water to move uniformly upwards to the filter bed.
   Properties: clean, free from flat and thin shapes, hard, round, durable and ρ_s = 1600 kg/m^3
D) Underdrain system: The objectives of this layer:
   i. To collect the filtered water.
   ii. To distribute the washing water evenly.

Mathematical equation of filtration process:

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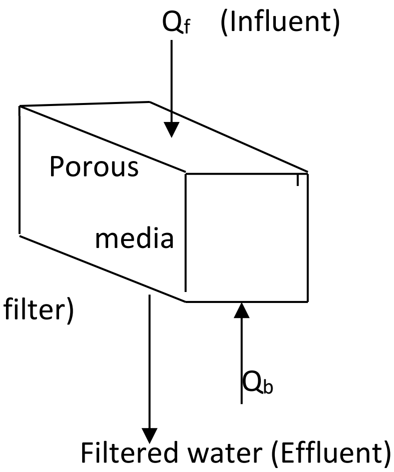
Q_f = Filtration discharge (flow through one filter)



$$Q_f = A_s \times V_f$$

A_s =surface area of the filter.

V_f = Filtration rate (m/day).

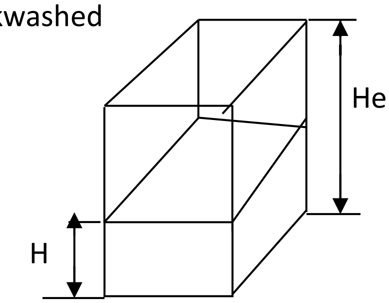
Q_b= Backwash discharge (Washing water for one filter)

$$Q_b = A_s \times v_b$$

v_b = Backwash rate

$$Q_b = \frac{Volume\ of\ washing\ water}{Time\ required\ for\ washing} = \frac{Q}{V}$$

* An expansion space for the filter media to move when backwashed



$$\frac{H_e}{H} = \frac{(1-n)}{(1-n_e)}$$

H = Height of the filter bed.

H_e = Height of the expanded filter bed when backwashed

n = Porosity of the clean filter bed.

n_e = Porosity of the expanded filter bed, $\left(n_e = \left(\frac{v_b}{v_s}\right)^{0.22}\right)$

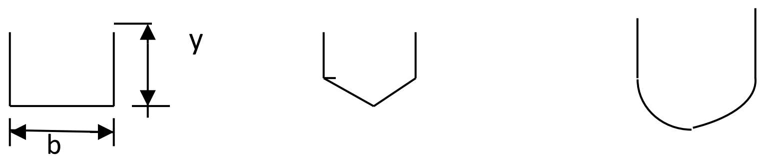
v_b = Backwash velocity rate.

v_s= Settling velocity of the filter media (Stoke 's settling velocity)

E) Trough: The objectives of this lateral channel to collect the backwash water.

Types of the troughs

Flat bottom V- bottom Rounded



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$$y = 1.73 \times \sqrt[3]{\frac{q_t^2}{g \times b^2}}$$

y = Height of the trough (m).

b = Width of the trough (m).

g = Acceleration of gravity (m/ sec^2)

q_t = Backwash discharge reaching one trough (m^3 /sec), $\left(q_t = \frac{Q_b}{No.of\ troughs}\right)$

F) Gullet: The objectives of this main channel to collect the backwash water from the troughs.

Design Criteria

1) Filtration rate (v_f) = 120 -360 m/day.
2) Backwash rate (v_b) = 0.15 -0.9 m/min (216-1296 m/day).
3) Surface area (A_s) = 5 – 200 m^2
4) Washing time = 5 -15 min.
5) Horizontal distance for backwash water to reach the trough is not to exceed one meter.
6) Filtration run = 12-72 hr (if the turbidity of the influent is: a. Low–long run, b. High–short run).
7) Total head loss = 2.7 – 3.7 m

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Operation Problems In RSFs

1) **Air Binding:**
    a) 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.
    b) A stage is finally reached when the frictional resistance offered by the filter media exceeds the static head of water above the 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.
    c) 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.
    d) To avoid such troubles, the filters are cleaned as soon as the head loss exceeds the optimum allowable value.

2) **Mud accumulation:** 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) **Sand Incrustation (cracking of filter):** to solve this problem a-Skimming b-Use anthracite as a top layer on the filter Media-Carbonation. 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 by:

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

Backwashing of Rapid Sand Filter

1) For a filter to operate efficiently, it must be cleaned before the next filter run. If the water applied to a filter is of very good quality, the filter runs can be very long. Some filters can operate longer than one week before needing to be backwashed. However, this is not recommended as long filter runs can cause the filter media to pack down so that it is difficult to expand the bed during the backwash.
2) Treated water from storage is used for the backwash cycle. This treated water is generally taken from elevated storage tanks or pumped in from the clear well.

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3) The filter backwash rate has to be great enough to expand and agitate the filter media and suspend the floc in the water for removal. However, if the filter backwash rate is too high, media will be washed from the filter into the troughs and out of the filter.

When is Backwashing Needed?

The filter should be backwashed when the following conditions have been met:

1) The head loss is so high that the filter no longer produces water at the desired rate; and/or
2) Floc starts to break through the filter and the turbidity in the filter effluent increases; and/or
3) A filter run reaches a given hour of operation.

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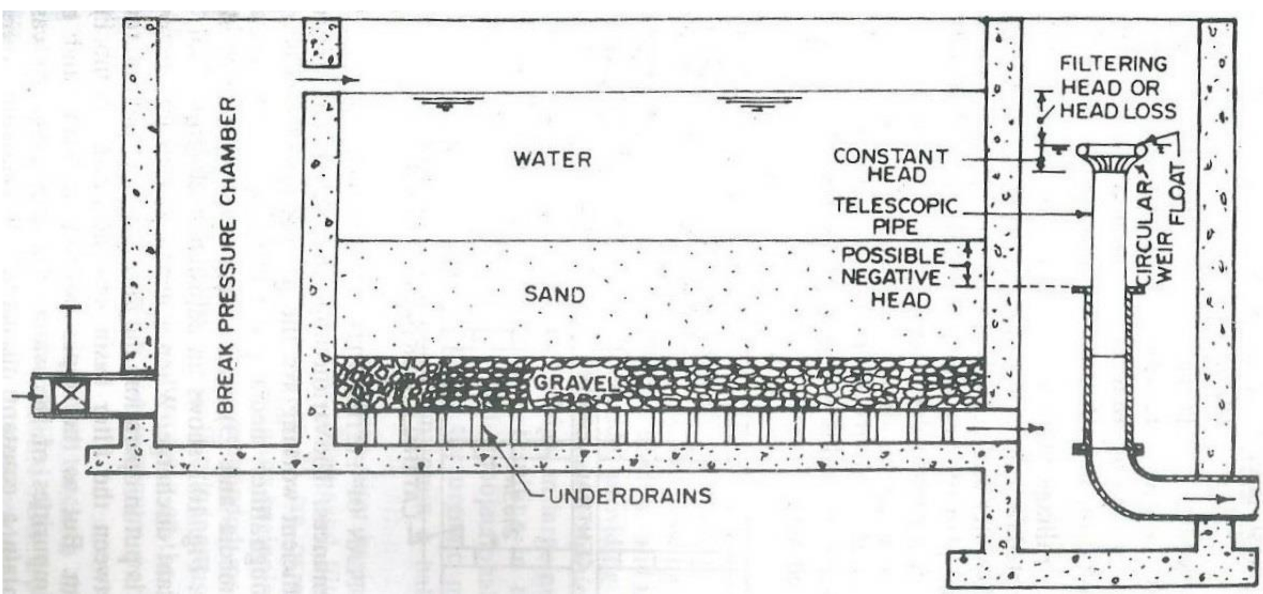
Principles of Slow Sand Filtration

1) In slow sand filter impurities in the water are removed by a combination of processes: sedimentation, straining, adsorption, and chemical and bacteriological action.
2) During the first few days, water is purified mainly by mechanical and physical-chemical processes. The resulting accumulation of sediment and organic matter forms a thin layer on the sand surface, which remains permeable and retains particles even smaller than the spaces between the sand grains.
3) As this layer develops, it becomes living quarters of vast numbers of microorganisms which break down organic material retained from the water, converting it into water, carbon dioxide and other oxides.
4) Most impurities, including bacteria and viruses, are removed from the raw water as it passes through the filter skin and the layer of filter bed sand just below. The purification mechanisms extend from the filter skin to approx. 0.3-0.4 m below the surface of the filter bed, gradually decreasing in activity at lower levels as the water becomes purified and contains less organic material.
5) When the microorganisms become well established, the filter will work efficiently and produce high quality effluent which is virtually free of disease carrying organisms and biodegradable organic matter. They are suitable for treating waters with low colors, low turbidities and low bacterial contents.



Slow sand filter.

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Sand Filters vs. Rapid Sand Filters

1) **Base material:** In SSF it varies from 3 to 65 mm in size and 30 to 75 cm in depth while in RSF it varies from 3 to 40 mm in size and its depth is slightly more, i.e. about 60 to 90 cm.
2) **Filter sand:** In SSF the effective size ranges between 0.2 to 0.4 mm and uniformity coefficient between 1.8 to 2.5 or 3.0. In RSF the effective size ranges between 0.35 to 0.55 and uniformity coefficient between 1.2 to 1.8.
3) **Rate of filtration:** In SSF it is small, such as 100 to 200 L/h/sq.m. of filter area while in RSF it is large, such as 3000 to 6000 L/h/sq.m. of filter area.
4) **Flexibility:** SSF are not flexible for meeting variation in demand whereas RSF are quite flexible for meeting reasonable variations in demand.
5) **Post treatment required:** Almost pure water is obtained from SSF. However, water may be disinfected slightly to make it completely safe. Disinfection is a must after RSF.
6) **Method of cleaning:** Scrapping and removing of the top 1.5 to 3 cm thick layer is done to clean SSF. To clean RSF, sand is agitated and backwashed with or without compressed air.
7) **Loss of head:** In case of SSF approx. 10 cm is the initial loss, and 0.8 to 1.2m is the final limit when cleaning is required. For RSF 0.3 m is the initial loss, and 2.5 to 3.5 m is the final limit when cleaning is required.

Item	SSF	RSF
Base material	Particle Size: 3-65 mm Depth: 20-75 cm	Particle Size: 30-40 mm Depth: 60-90 cm
Filter sand	D_{10}: 0.2-0.4 mm C_U: 1.8-3	D_{10}: 0.35-0.55 mm C_U: 1.2-1.8
Filtration rate	2.4-4.8 m/day	120-360 m/day
Flexibility	not flexible for meeting variation in demand	flexible for meeting reasonable variations in demand
Post treatment required	water may be disinfected slightly to make it completely safe	Disinfection is a must after RSF
Method of cleaning	Scrapping and removing of the top 1.5 to 3 cm thick layer is done to clean SSF	To clean RSF, sand is agitated and backwashed with or without compressed air
Loss of head	10 cm is the initial loss, and 0.8 to 1.2m is the final limit when cleaning is required	0.3m is the initial loss, and 2.5 to 3.5m is the final limit when cleaning is required

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SOLVED PROBLEMS

Problem 9.1: A WTP is designed to treat 48,000 m^3/day. For filtration 12 RSFs are used, each filter is designed with 2 troughs of a square cross-sectional area. The filtration rate is 160 m/day and the backwash rate is 864 m/day. Find

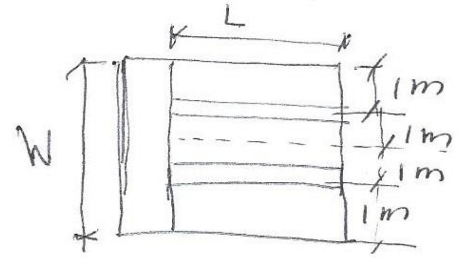
1) Dimensions of each filter, L and W (m) with or without washing? Also filter depth?
2) Dimensions of each trough, y and b (m) and gullet?
3) Volume of water (m^3) to wash 2 filters at the same time for 5 minutes?

Solution:

1) $\because\ n_b = Zero\ (All\ filters\ in\ operation\ i.e\ no\ washing)$

$$Q_f = \frac{Q_{Total}}{n-n_b} = \frac{48\times10^3}{12} = 4000\ m^3/day$$

$$Q_f = v_f \times A_s \Rightarrow A_s = \frac{4000\,\frac{m^3}{day}}{160\,\frac{m}{day}} = 25\ m^2 = L \times W$$



For two troughs, W=4 m,

Assuming maximum horizontal flow for backwashing water to reach the trough = 1 m

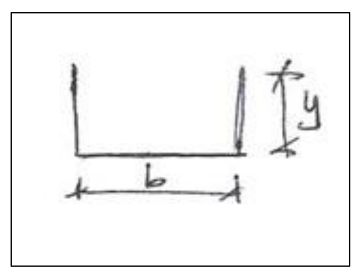
$$\therefore L = \frac{25}{4} = 6.25\ m$$

Check: total filter depth = Freeboard (0.5m) + Water head (1m) + Sand layer (1m) + Gravel layer (0.6m) + Underdrain (0.4m) = 3.5 m

So, use filter dimension (L = 6.25 m, W = 4 m, and H = 3.5 m)

2) Trough dimension:

$$q_t = \frac{Q_b}{No.of\ troughs} = \frac{A_s \times v_b}{2} = \frac{25\ m^2 \times \frac{864}{24\times3600}}{2} = 0.125\ m^3/sec$$



Assume y = b (Square cross section of the trough)

$$y = 1.73 \times \sqrt[3]{\frac{q_t^2}{g \times b^2}} = 1.73 \times \sqrt[3]{\frac{q_t^2}{g \times y^2}} \Rightarrow y^5 = (1.73)^3 \times \frac{q_t^2}{g} = (1.73)^3 \times \frac{0125^2}{9.81} \Rightarrow y = 0.38\ m = b$$

Gullet dimension:

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$$q_G = \frac{Q_b}{No.of\ Gullet} = \frac{A_s \times v_b}{1} = \frac{25\ m^2 \times \frac{864}{24 \times 3600}}{1} = 0.25\ m^3/sec$$

Assume y = b (Square cross section of the gullet)

$$y = 1.73 \times \sqrt[3]{\frac{q_G^2}{g \times b^2}} = 1.73 \times \sqrt[3]{\frac{q_G^2}{g \times y^2}} \Rightarrow y^5 = (1.73)^3 \times \frac{q_D^2}{g} = (1.73)^3 \times \frac{025^2}{9.81} \Rightarrow y$$
$$= 0.505\ m = b$$

3) $Water\ volume\ for\ washing = Q_b \times t \times n_b = 864 \frac{m}{day} \times 25\ m^2 \times \frac{5\ min}{60 \times 24} \times 2 = 150\ m^3\ (Washing\ water\ for\ two\ filters)$

$$Volume\ for\ one\ filter = \frac{150}{2} = 75\ m^3$$

Note: The ratio of water washing amount for one filter does not exceed 7% of the water filtration amount.

$$Volume\ of\ filtrated\ water = 4000 \frac{m^3}{day} \times 1 = 4000\ m^3$$

$$Ratio\ for\ one\ back\ washing = \frac{75}{4000} \times 100 = 1.875\% < 7\%\ \ O.K$$

Problem 9.2: A city has a population of 100,000 capita with an average rate of demand of 160 L/cap.day. Find the area of rapid sand filter? Assume an average filtration rate of 120 m^3/m^2.day of filter area, the filter length equal 1.5 width and filter area not exceed 40 m^2.

Solution:

$$Maximum\ daily\ demand = 1.8 \times 160 \times 10^{-3} \times 100000 = 28800\ m^3/day$$

$$Area\ of\ filters = \frac{28800}{120} = 240\ m^2\ \ No.of\ filters = \frac{240}{40} = 6\ filters$$

$$A_s = 40 = L \times W = 1.5W^2 \Longrightarrow W \approx 5.20\ m\ \&\ L = 7.8\ m$$

Problem 9.3: A flat bottom trough is to receive the wash water from a section of the filter which is 2 m wide and 3 m long. The wash water rate is 700 liters per min per m^2. If the water is to have a depth of 25 cm at the upper end of the trough, what should be the dimensions of the trough?

Solution:

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$$Q_b = v_b \times A_s = 700 \times 2 \times 3 = 4200 \frac{L}{min} = 4.2 \frac{m^3}{min} = 0.07\ m^3/sec$$

$$y = 1.73 \times \sqrt[3]{\frac{q_t^2}{g \times b^2}} \Longrightarrow 0.25 = 1.73 \times \sqrt[3]{\frac{0.07^2}{9.81 \times b^2}} \Longrightarrow b = 0.406\ m$$

Assume freeboard = 5 cm, the depth of trough will be = 25 + 5 = 30 cm

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