Ministry of Higher Education and Scientific Research
Southern Technical University
Basrah Engineering Technical College

Water Pollution Control

For
Students of forth class
Department of Environment and Pollution Engineering
Basrah Engineering Technical College

FIGURE 1.
Fimbriae seen on *E coli.*

Source: Hybrid Medical Animation / Photo Researchers, Inc.

By

Dr. Ihsan A. Abdulhussein

Assistant Prof.
Department of Environment and Pollution Engineering
Basrah Engineering Technical College

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Flow through porous media

FILITRATION

Fifth modular unit

Rationale :-

Filtration of suspensions through porous media, usually sand, is an important stage of the treatment of potable waters to achieve final clarity. Although about 90 per cent of the turbidity and color are removed in coagulation and sedimentation a certain amount of floc is carried over from settling tanks and requires removal. Sand filtration is also employed to provide tertiary treatment of 30:20 standard sewage effluents. Other uses of flow through porous media include ion-exchange beds, adsorption beds and absorption columns where the aim is not to remove suspended matter but to provide contact between two systems.

The Text

Filtration

a- Purpose and definition:

Filtration of water is defined as the separation of colloidal and fine particles from water by passage through a porous medium, usually sand, granular coal, or granular activated carbon. The suspended particles are removed during filtration range in diameter from 0.001 to 50 microns and larger.

b- Granular Filtration Theory:

1- The particles are removed by simple **mechanical screening** because the particles are larger than the smallest opening through which water flows.
2- The pore spaces between the grains of granular material are small, and the water velocity through the interstices is also small. If the mass and diameter of the particles is large enough, it will **settle** through the short distance from the water to the particle.
3- The stream lines of water flowing through the interstices bend as the water passes around the granular material; particles are brought into contact with one another. This mixing causes them to **flocculate** and grow large in size.
4- Bending stream lines also causes smaller particles to pass near enough to the grains of filter material to be **intercepted.**
5- The particles have sufficient mass that they cannot follow the flow path with the stream lines, and their trajectory causes them to **impact** on granular material.

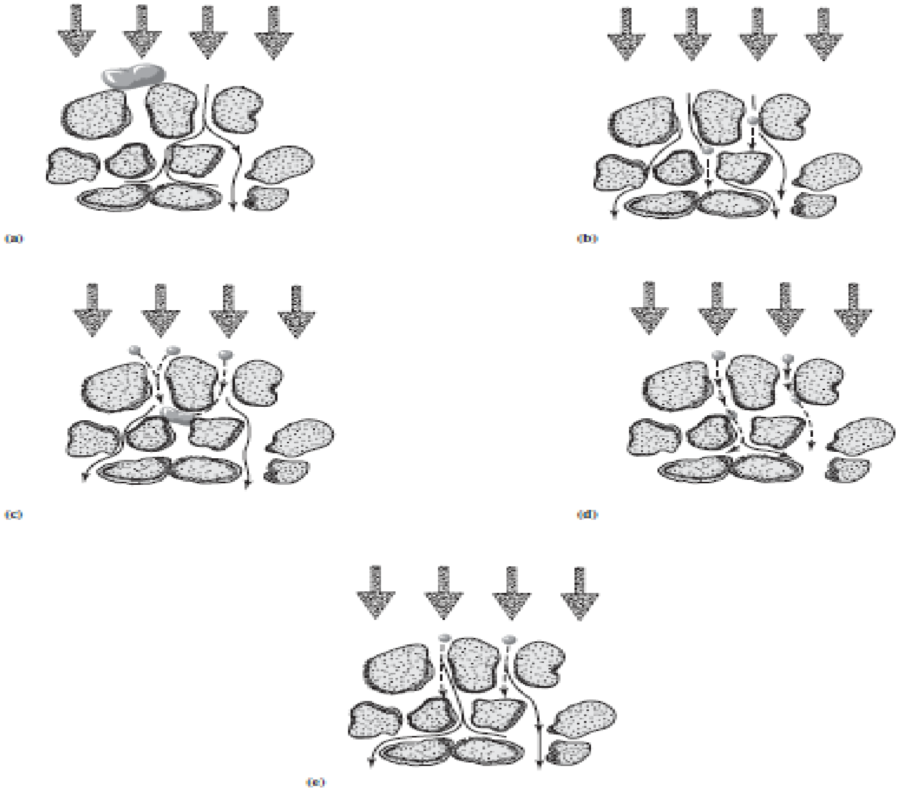


FIGURE 11-4
Mechanisms of granular filtration: (*a*) mechanical screening, (*b*) sedimentation, (*c*) flocculation, (*d*) interception, (*e*) impaction. Dashed line is particle trajectory. Solid line is water streamline (flow path).

c- Types of filters:

1- Gravity filter → i- Slow sand filters
ii- Rapid gravity filters

2- Diatomite filters (used for swimming pool)

3- Pressure filters → i- Conventional down flow filter
ii- High-rate down flow filters
iii- Up flow filters
iv- Up flow continuous backwash sand filters.

Filter operation and control: (Rapid gravity filters)

1- Starting the filter:

Fill with water from bed of filter to dismissed air voids without any moving or disturb of the sand media.

2- Repairing period:

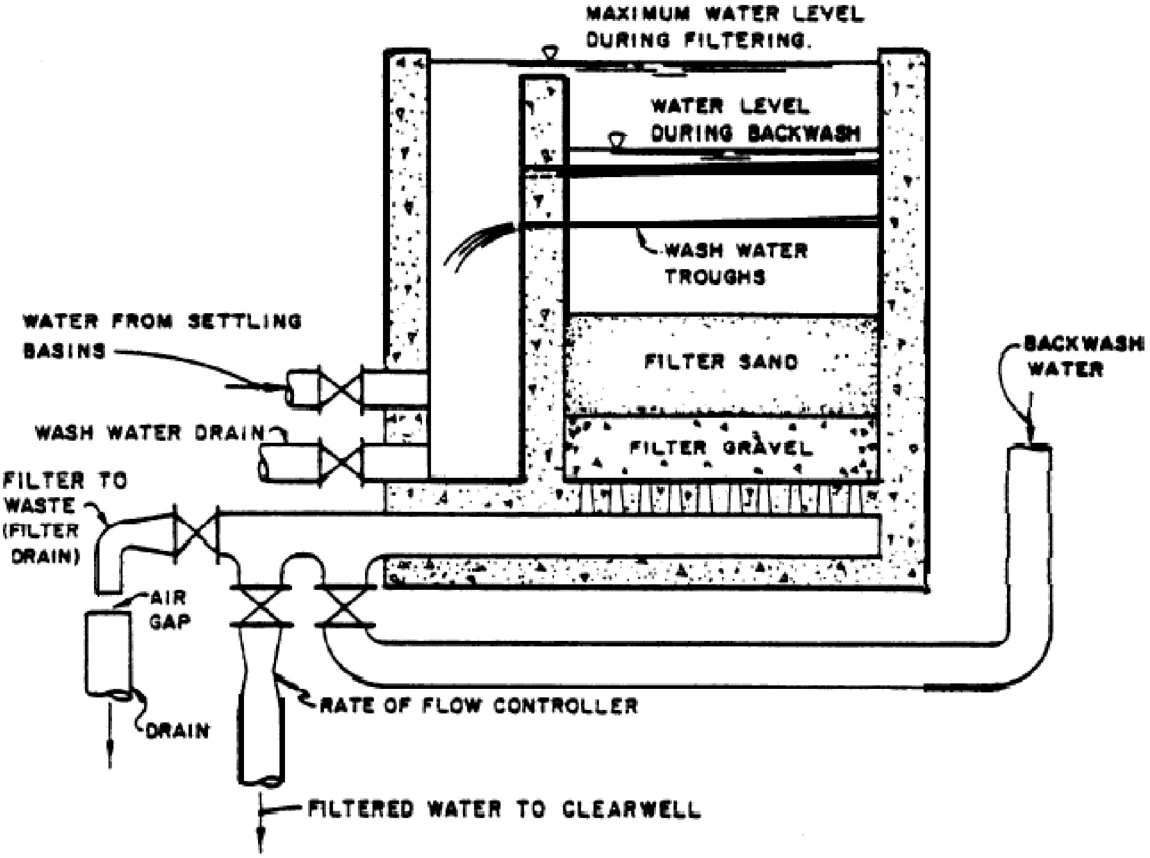
Open valve (1) and (3) → water seeps up to bed of filter and drain the product water (10 → 15 minutes)

3- Filtration period:

Open valve (1) and (2) → water seeps up to bed of filter then to the ground tank collection (16 -36 hrs.)

4- Washing process:

Open valve (4) and (5) → water rise bed to top of the trough channel to the drainage system (V= 0.5- 0.8 m/min) (10-15 minutes)



SCHEMATIC OF
RAPID SAND FILTER
OPERATIONAL CONTROLS

Design Consideration

1- Comparison of slow sand and rapid gravity filters:

Item	Slow Sand	Rapid Gravity Sand
1- Rate of filtration	2500-6000 (l/m^2/day)	120000-150000 (l/m^2/day)
2- Size of unit	2000-4000 m^2 in area	(4x5) to (8x10) m^2/unit
3-Depth of filter media	Sand → 80-100 cm Gravel → 25-30 cm	Sand → 60-75 cm Gravel → 45-60 cm
4-Size of sand	Effective size → 0.35 mm Uniformity coeff. → 1.75	Eff. Size → 0.5-0.7 mm Unif. Coeff. → 1.25-1.35
5-Grain size dist.	Uniform	Stratified with small grain at the top
6-Under drainage system	Open jointed pipes covered with blocks	(i)Mainfold and laterals (ii)Wheeler bottom (iii)Diffuseer plate
7-Head loss	Initially → 0.1 m Finally → 1 m	Initially → 0.2 m Finally → 3 m
8-Lengh of run	20-40 days	24 to 48 hrs.
9-Pentration of S.S	Superficial	Deep
10-Method of cleaning	Scraping and washing	Back washing
11-Water required for cleaning	0.2 to 0.6 % of water filtered	2% to 6% of water filtered
12-Preparotory treatment	Plain sedimentation	Floccuaation and settling
13-Cost of construction	Higher	Low
14-Cost of operation	Lower	Higher
15-Depreciation of plant	Lower	Higher

2- Flow through Sand Bed:

The friction loss through bed of particles of uniform size (d) can be calculated by Carmen-Kozeny equation:

$$h_f = \frac{f.L.(1-e)v_s^2}{g.d.e^3}$$

Where; h_f=Friction loss, m

L= depth of filter, m

e= Porosity of bed

v_s= filtering velocity ,i.e., the velocity of water just above the bed (total flow Q to the filter divided by the area of filter), m/s

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

d= diameter of filter media grains, m

f= coefficient of drag around the particles

f= 150 $\frac{(1-e)}{R}$+1.75   (laminar flow)

Where, R= $\frac{\Phi\rho V s d}{\mu}$

ρ= density (kg/m^3); μ= dynamic viscosity (N.s/m^2)

Φ= shape factor (0.75-0.85)

3-Back wash (filter washing) Hydraulics:

To clean the interior of the bed, it is necessary to expand it so that the granules are no longer in contact with each other, thus exposing all surfaces for cleaning. To hydraulically expand a porous bed, the head loss must be at least equal to the buoyant weight of the particles in the fluid. For a unit area of filter this expressed by:

h_{fb} = L(1-e) $\frac{\rho 1-\rho}{\rho}$ -------------------------(1)

Where; h_{fb}= head loss required to initiate expansion, m

L= bed depth, m

e= porosity of medium

ρ1= density of the medium, kg/m^3

ρ= density of water; kg/m^3

The head loss through an expanded bed is essentially unchanged because the total buoyant weight of the bed is constant. Therefore,

Weight of the packed bed = Weight of bed fluidized

L(1-e) $\frac{\rho 1-\rho}{\rho}$= L_{fb}(1-e_{fb})$\frac{\rho 1-\rho}{\rho}$---------------(2)

or L_{fb}= L.$\frac{(1-e)}{(1-e_{fb})}$

Where, L_{fb} = Depth of fluidized bed

e_{fb} = Porosity of fluidized bed

The relation between backwash velocity and particle settling velocity is given by

e_{fb}=$[\frac{V_b}{V_t}]^{0.22}$ $\longrightarrow$ $L_{fb}= \frac{L\,(1-e)}{1-[\frac{V_b}{V_t}]0.22}$

V_b: Back wash velocity

V_t: settling velocity

4-Minimum Number of Filters:

Discharge (Q) < 8000 m^3/d → Min. No. =2

> 8000 m^3/d → Min. No. =4

For large plants N=0.0195 $(Q)^{0.5}$

Where, N=Total number of filters

Q= Maximum design flow rate, (m^3/d)

5- Filtration Rate:

Conservation design filtration rates are:

Rapid sand filter → 7.5 m/hr.= 180 m/d

Dual –media filter → 15 m/hr.= 360 m/d

Deep coarse monomedium → 25 m/hr.= 600 m/d

6- Area of Filter Bed:

The area of a filter bed may be estimated as:

$$A = \frac{Q}{N.q}$$

Where, A= Area of filter bed, m^2

Q = Maximum daily flow rate, m^3/d

q = Filtration rate, $m^3/m^2/d$

N= No. of filter beds

Illustrated Problems

Example 1: In the rapid sand filter bed, the water is passed through sand bed at a filtering velocity of 0.5 m/hr. The sand grains are 0.25mm in diameter with shape factor of 0.85 and settling velocity equal to five times backwash velocity. The depth of filter bed is 0.9m and porosity is 0.5.

Determine the followings:

a. Head loss through the filter bed.
b. Expanded porosity (e_{fb}).
c. Resulting expanded depth (L_{fb}).

Assume $\mu=1.002x10^{-3}$ kg/m.sec.

Solution:

Velocity through filter=0.5 m/hr. = $1.39x10^{-4}$ m/s

a- $R=\frac{\emptyset \rho V_s d}{\mu}=\frac{(0.85x1000x1.39x10^{-4}-4x0.25x10^{-3})}{(1.002x10^{-3})}$

R=0.029741 <1 (Laminar flow confirmed)

Friction factor= $150x\frac{(1-0.5)}{0.0297}+1.75=2527$

Thus, $h_f=\frac{f.L.(1-e)v_s^2}{g.d.e^3}$

$\therefore h_f=\frac{2527*0.9*(1-0.5)*(1.39*10^{-4})2}{0.5^3*9.81*0.25*10^{-3}}$ = 0.0716 m= 7.16 cm

b- $e_{fb}=(\frac{Vb}{vt})^{0.22}$

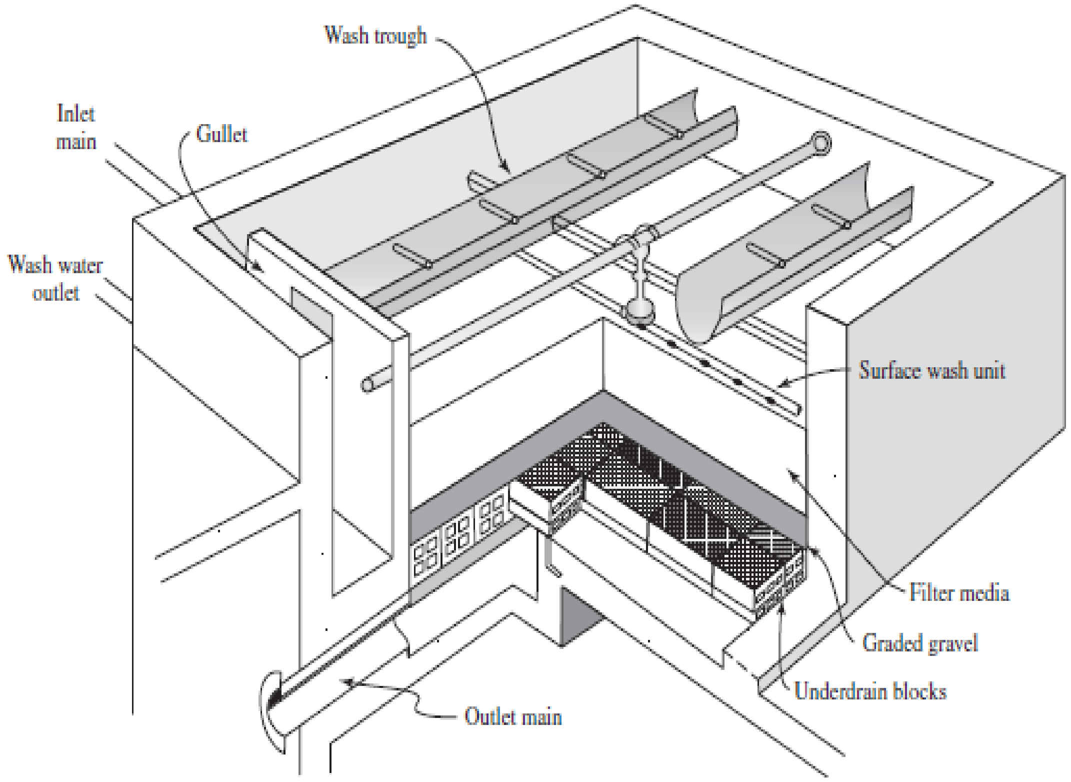
$V_t=5\ v_b$

$\therefore\ e_{fb}=(\frac{Vb}{5\ Vb})^{0.22}=(\frac{1}{5})^{0.22}=0.7$

c- $L_{fb}=Lx\frac{1-e}{1-efb}=0.9x\frac{1-0.5}{1-0.7}=1.5$ m

Example 2: In designing of rapid gravity sand filter for water treatment plant, the following data are given: discharge=$15*10^6$ L.P.d, rate of filtration = 150000 L/m^2/day. Find out and check for the following:

i- Filter area required and number of units if the size of each unit is (4.4*5.7 m).
ii- Total area and number of perforation in one unit if the diameter of perforation is 9 mm.
iii- Total cross sectional area, number, and diameter of laterals in one unit if the spacing between laterals is 15 cm.
iv- Area and diameter of central manifold.
v- Length of lateral.
vi- Number and spacing of perforations per lateral.
vii- Quantity of wash water required per filter bed and rate of flow if back wash time is 10 minutes.
viii- Dimension of wash water troughs if the spacing is 1.5 m and width of trough equal to 0.3 m.



Solution:

i. Q= $15*10^6$ liter/d=150000 m^3/d > 8000 m^3/d

Hydraulic loading= 150000 liter/m^2/d

Total Filter Area required = $\frac{15*10^6}{150000}$ = 100 m^2

No. of filters = $\frac{100}{4.4*5.7}$ = 3.98 ≈ 4 (o.k)

Or: No. of filters= $\frac{Q}{A*q} = \frac{15000000}{(4.4*5.7)*150000} = 3.98 = 4$

Add two units, so total = 6

ii . Total area of perforations=0.003*Filter Unit Area

= $3*10^{-3}*4.4*5.7$= 0.0753 m^2 = 753 cm^2

Total No. of perforations= $\frac{753}{\frac{\pi}{4}(0.9^2)}$ = 1183

iii . X-sectional tree lateral= 3*753= 2259 cm^2

No. of lateral=$\frac{2*5.7*100}{15}$ = 76

X- Sectional treatment lateral =$\frac{2259}{76}$ = 29.7 cm^2

Diameter of lateral = $\sqrt[2]{(29.72*4)/\pi} = 6.15$ cm Provide 7.5 cm

iv. Area of manifold = 2 *2259 = 4518 cm^2

Diameter of center manifold = 75.8 cm

v. Length of lateral = $\frac{1}{2}$ (4.4 – 0.75)

= 1.82cm

vi. No. of perf. = $\frac{1183}{76} \boxed{=} 16$

Spacing = $\frac{1.82*100}{16} \boxed{= \ 11.35}$ cm

vii. Wash water = 0.06 * 15 * 10^6 = 900m^3

wash water / filter = 900/6 = 150m^3

Rate of flow = $\frac{150}{10*60} \boxed{= 0.25} \frac{m3}{s}$

viii. No. of troughs = 4.4 / 1.5 = 3
Q = 1.376 b$h^{3/2}$ b=0.4 ∴ h = 0.3

Example 3: Determine the area of each individual filter and the plan (horizontal) dimensions of a filter box. Use the filtration rate of 216 m^3/m^2/d, and the maximum daily design flow rate is 18400 m^3/d.

Solution:

a-The initial estimate of number of filters is calculated as follow:

$$N=0.0195\ (Q)^{0.5} = 0.0195\ (18400)^{0.5} = 2.65$$

However, the design guidance for plants with a design capacity greater than 8000 m^3/d is a minimum of four filters.

Comment: Four filters provide more flexibility in operation.

b. The area of a bed is:

$$A = \frac{Q}{N.q} = \frac{18400}{(4)*(216)} = 21.229 \text{ or } 21.3 \text{ m}^2\text{/filter}$$

c. Redundancy capacity for the maximum day with one filter out of service must be provided. The choices are:

1. Increase the number of beds to five and reduce the area.

2. Increase the number of beds to six and reduce the area.

3. Maintain the number of beds at four but make the area larger. This allows for a lower q during average conditions and meets the design loading rate with one bed out of service on the maximum day.

4. Switch to a dual-media filter that would allow a higher loading rate.

d. Because of construction and operational considerations, filters are built in pairs. Thus, alternative (1) is eliminated. Alternative (2) would be acceptable but would have a capital cost 50% greater than the four-filter system. Without switching to dual media, option 3 offers the most economical alternative.

e. If each filter is increased by 1/3, the filtration rate with one filter out of service would be:

$$q = \frac{18400}{(3)(1.333)(21.3m^2)} = 216.5 \text{ m}^3/\text{m}^2/\text{d}$$

Therefore, for a trial calculation assume the area of one filter is $(1.3333)(21.3 \text{ m}^2) = 28.4 \text{ m}^2$.

Example 4: Estimate the clean filter headloss of new sand filter with sieve analysis given in the table below and determine if it is reasonable. Use the following assumptions: loading rate is 216 $\text{m}^3/\text{d}/\text{m}^2$, specific gravity of sand is 2.65, the shape factor is 0.82, the bed porosity is 0.45, the kinematic viscosity is 1.307×10^{-6} m^2/s, and the depth of sand is 0.5 m.

Solution:

The headloss through a clean stratified-sand filter with uniform porosity is estimated using the equation described by Rose (1945):

$$h_L = \frac{1.067(v_a^2)(D)}{(\emptyset)\,(g)(e)^4}\sum\frac{(C_D)(f)}{d_g}$$

Where, h_L = frictional headloss through the filter, m

v_a = approach velocity (also known as *face velocity*, *filtration rate*, or *loading rate*), m/s (or $m^3/s.\ m^2$ of surface area)

D = depth of filter sand, m

C_D = drag coefficient

f = mass fraction of sand particles of diameter

d_g= geometric mean diameter of sand grains, m

= $\sqrt{d_1 d_2}$

d_1, d_2= diameter of upper and lower sieve openings, mm

φ= shape factor

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

e = porosity

The computations are shown in the table below.

Sieve No.	%Retained (*f*)	dg, m	R	CC_D	$\sum\frac{(C_D)(f)}{(dg)}$
8-12	5.3	0.002	3.137	9.684551	256.64
12-16	17.1	0.00142			
16-20	14.6	0.001			
20-30	20.4	0.000714			
30-40	17.6	0.000505			
40-50	11.9	0.000357			
50-70	5.9	0.000252			
70-100	3.1	0.000178*			
100-140	0.7	0.000126			
				Total=	75025

In the first two columns, the grain size distribution from sieve analysis is rearranged to show the fraction retained between sieves. The third column is the geometric mean diameter of the sand grain computed from the upper and lower sieve size. The fourth column is the Reynolds number computed from equation below with the correction for non-spherical sand grains. For the first row,

$$R = \frac{(\varphi)(d)(v_a)}{v} = \frac{(0.82)(0.002m)(0.0025\frac{m}{s})}{1.307 * 10^{-6}\ m^2/s} = 3.137$$

The filtration velocity of 0.0025 m/s is the conversion of the filtration loading rate to compatible units:

$$v_a = \frac{216\ \text{m}^3/\text{d m}^2}{86{,}400\ \text{s/d}} = 0.0025\ \text{m/s}$$

The drag coefficient is calculated in column 5 using the following equations depending on the Reynolds number.

$$C_D = \frac{24}{R} + \frac{3}{R^{1/2}} + 0.34 \qquad for\ R > 0.5$$

$$C_D = \frac{24}{R} \qquad for\ R < 0.5$$

For the first row,

$$C_D = \frac{24}{\mathbf{R}} + \frac{3}{\mathbf{R}^{1/2}} + 0.34$$
$$= 7.6507 + 1.6938 + 0.34 = 9.6846$$

The final column is the product of the fractional mass retained and the drag coefficient divided by the diameter. For the first row,

$$\frac{(C_D)(f)}{d} = \frac{(9.6846)(0.053)}{0.002} = 256.64\,\text{m}^{-1}$$

The last column is summed and the head loss calculated using the following equation:

$$h_L = \frac{1.067(0.0025\ \text{m/s})^2(0.5\ \text{m})}{(0.82)(9.81\ \text{m/s}^2)(0.45)^4}(75{,}025\ \text{m}^{-1})$$
$$= (1.0119 \times 10^{-5}\,\text{m}^2)(75{,}025\,\text{m}^{-1}) = 0.76\ \text{m}$$

Test 1:-

Circle the correct answer:-

1. **Property of soil to allow water to pass through it, is known as**

a- Perviousness
b- porosity
c- Permeability
c- transmissibility

2. **Capacity of soil to absorb moisture, is generally known as:-**

a- Permeability
b- porosity
c- Infiltration capacity
d- perviousness

3. **To remove very fine suspended particles from water, the method adopted is:**

a- screening
b- sedimentation
c- boiling
d- filtration

4. **After cleaning a slow sand filter, filtered water is not used for :**

a- 6 -12 hrs.
b- 12-18 hrs.
c- 18-24 hrs.
d- 24-36 hrs.

5. **Efficiency of removing bacteria's from raw water by slow sand filter, is :**

a- 80-81%
b- 98-99%
c- 90-97%
d- 85-86%

6. Filtration is a :

a- mechanical method b- chemical method

c- physical method d- other method

7. In rapid gravity filter:

a- raw water from the source is supplied
b- Disinfected raw water is supplied
c- Raw water passed through coagulation tank is supplied
c- none of these

8. Distribution of wash water is provided in:

a- Sedimentation tank b- slow sand filter
c- Rapid gravity filter d- all of these

9. A high velocity of wash water is required for:

a- Rapid gravity filter with strainers
b- Rapid gravity filter without strainers
c- Slow sand filter with strainers
d- Slow sand filter without strainers

10- Rapid gravity filters can only remove bacterial impurities up to a maximum of :

a- 50% b- 60% c- 75% d- 90%

Test 2 :-

A rapid sand filter is required to treat a flow of 0.50 m^3 per second . The filtration rate is 120 m^3 per day per m^2 of filter area and it is provided that the filtration rate with one filter washing is not to exceed 150 m^3 per day per m^2 of filter area . Determine the number of units and the area of each unit to satisfy these conditions .

Each filter is washed for 5 minutes every 24 hours at a wash rate of 10 mm per second per m^2 of filter area . The filter remains out of operation for a total interval of 30 minutes per day . Calculate the percentage of filter output used for washing .

key Answer :-

1- Test 1:-

1. a
2. c
3. d
4. d
5. b
6. a
7. c
8. c
9. b
10. d

If you:-

- Got 9 or more you do not need to proceed.
- Got less than 9 you have to study this modular unit well.

2- Test 2:-

Maximum flow rate = (0.5 x 60 x 60 x24) m^3 per day

= 43200 m^3 per day

Note : the rate of filtration can also be expressed as m^3 per day per m^2 of filter area because of the relation 1 m^3 = 1000 liters .

Thus 120 m^3 per day per m^2 of filter area is equivalent to ($\frac{120 \; x \; 1000}{24}$) = 5000 liters per hour per m^2 of filter area .

Filter area on the basic Of maximum filtration rate = $\frac{43200}{150}$ = 288 m^2

Filter area on the basis of maximum filtration rate = $\frac{43200}{120}$ = 360 m^2

Area of one filter unit = (360 – 280) 72 m^2

Total numbers of filters = $\frac{Maximum\ filter\ area}{Area\ of\ one\ unit}$

= $\frac{360}{72}$ = 5

Now , each unit of filter is working at the filtration rate of 120 m^3 per day per m^2 of filter area and the operation of filter is out of order for a period of 30 minutes .
Hence , the total working period per day of each filter is (24 – 0.5) = 23.5 hours .

Output of each unit per day = Area x Filtration Rate x $\frac{Working\ period}{24}$

$$= (72 \times 120 \quad \times \frac{23.5}{24} \quad)$$

$$= 8460 \ m^3$$

Wash rate = 10 mm per second per m^2 of filter area

= (10 x 10^{-3} x 60)m per minute per m of filter area .

Washing period = 5 minutes

Wash – Water required per day = Area x Wash rate x Washing period

$$= 72 \times (10 \times 10^{-3} \times 60) \times 5$$

$$=216 \ m^3.$$

Percentage of filter output used for washing = $\frac{Wash-water\ erquired}{output\ of\ each\ unit}$ x 100

$$= \frac{216}{8460} \times 100$$

$$= 2.55 \ \%.$$

If you:-

- Got 9 or more, so congratulation your performance, go on studying modular unit three.
- Got less than 9, go back and study the second unit; or any part of it; again, and then do the post test again.

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