ENVE 301

Environmental Engineering Unit Operations

CHAPTER: 12

Filtration

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FILTRATION

It is a solid-liquid separation process in which the liquid passes through a porous medium to remove as much fne suspended solids as possible.

Applications:

In water treatment plants,

a polishing step to remove small flocs or precipitant particles not removed in settling

Under certain conditions, it may serve as the primary turbidity removal process called DIRECT IN-LINE FLOCCULATION

Flocculation tank and sedimentation tank are omitted

Applicable for low turbid water

In wastewater treatment plants,

commonly used for the removal of residual biological floc in settled effluents from secondary treatment before disinfection or discharge to receiving water bodies

to remove residual precipitates from the metal salt or lime precipitation or phosphate

FILTRATION

Actual filtration
process by which the water is cleaned

Backwashing
cleaning of filter medium

During filtration;

Water or wastewater containing suspended matter is applied to the top of the filter bed

As the water (or wastewater) filters through the porous medium, the suspended matter in the fluid is removed by a variety of mechanisms. These mechanisms are :

Straining , Sedimentation, Impaction, Interception, Adhesion, Adsorption, Flocculation, Biological growth

MECHANISMS FOR THE REMOVAL OF SUSPENDED MATTER IN A GRANULAR-MEDIUM FILTER

STRAINING

SEDIMENTATION

INTERCEPTION

ADHESION

FLOCCULATION

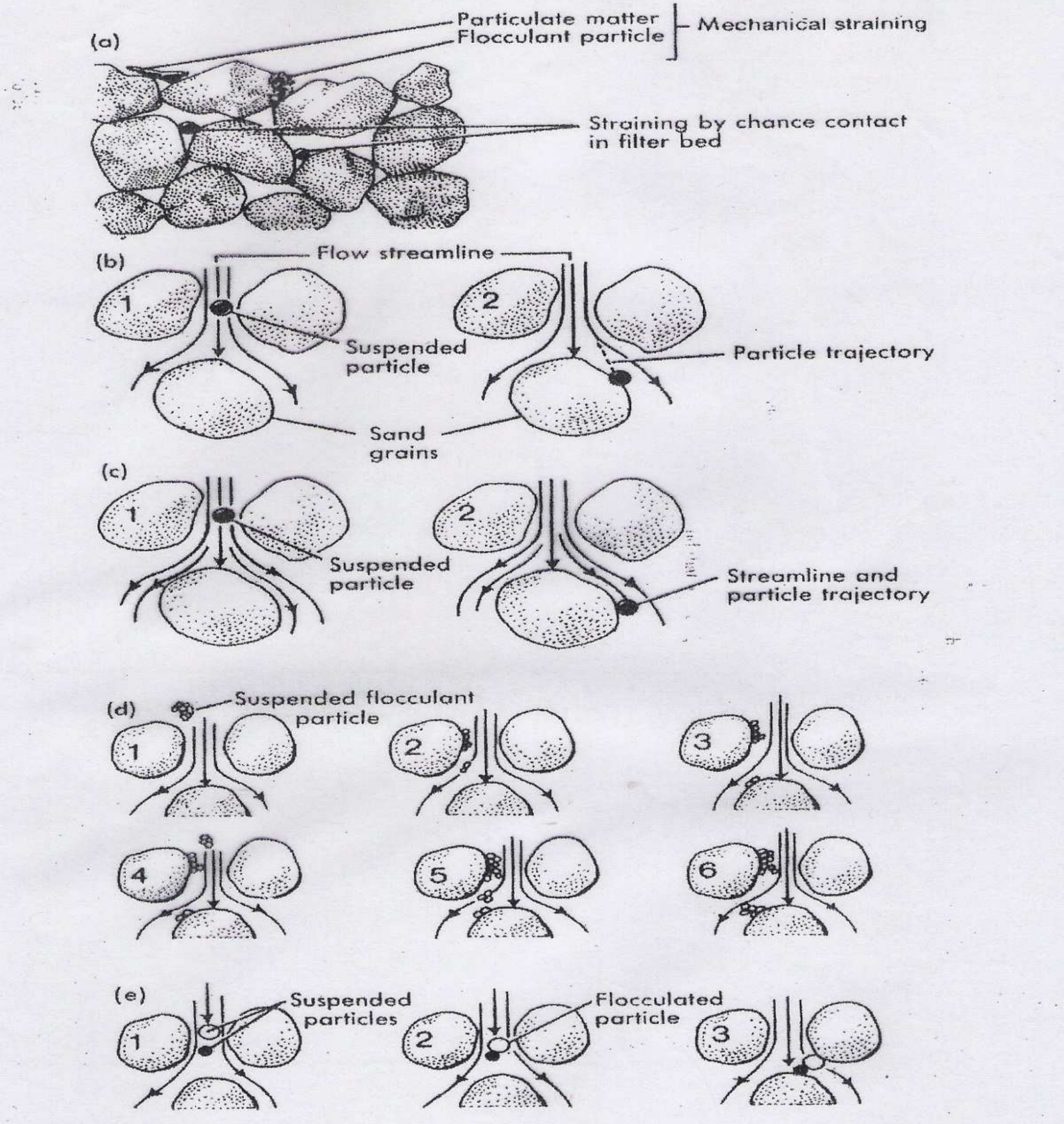


FIGURE 12.26

Definition sketch for the removal of suspended matter in a granular-medium filter. (a) By straining, (b) By sedimentation and inertial impaction, (c) By interception,

MECHANISMS FOR THE REMOVAL OF SUSPENDED MATTER IN A GRANULAR-MEDIUM FILTER

1) Straining : particles > pore space of filtering medium → strained out mechanically

particles < pore space of filtering medium → are trapped in filter by chance contact

2) Sedimentation : Particles settle on the filter medium

3) Impaction : Heavy particles will not follow the flow streamlines

4) Interception : Particles moving along in the streamline are removed when they come in contact with the surface of filtering medium

MECHANISMS FOR THE REMOVAL OF SUSPENDED MATTER IN A GRANULAR-MEDIUM FILTER

5) Adhesion : Flocculant particles become attached to the surface of the filtering medium as they pass by

6) Adsorption (chemical or physical or both) :
Once a particle has been brought in contact with the surface of the filtering medium or with other particles.

7) Flocculation : Large particles overtake smaller particles, join them , and form still larger particles. These are than removed by one or more of the above removal mechanisms

8) Biological growth : Biological growth within the filter will reduce the pore volume and may enhance the removal of particles with any of the above removal mechanisms.

Substances collected on the surface of the filter medium
+
available nutrient

Organisms begin to grow on the surface of filter

A mat is formed containing slimy ''*zoogleal*'' organisms known as '' *Schmutzdecke*''.

helps in the straining action of the filter, but must be removed when the headloss through the filter is high.

undesirable in rapid sand filter encourages formation of mud balls during backwashing.

TABLE 6-12

Mechanisms operative within a granular-medium filter that contribute to the removal of suspended materials[a]

Mechanism	Description
1. Straining[b]	
a. Mechanical	Particles larger than the pore space of the filtering medium are strained out mechanically
b. Chance contact	Particles smaller than the pore space are trapped within the filter by chance contact
2. Sedimentation[b]	Particles settle on the filtering medium within the filter
3. Impaction[b]	Heavy particles will not follow the flow streamlines
4. Interception[b]	Many particles that move along in the streamline are removed when they come in contact with the surface of the filtering medium
5. Adhesion[b]	Flocculant particles become attached to the surface of the filtering medium as they pass by. Because of the force of the flowing water, some material is sheared away before it becomes firmly attached and is pushed deeper into the filter bed. As the bed becomes clogged, the surface shear force increases to a point at which no additional material can be removed. Some material may break through the bottom of the filter, causing the sudden appearance of turbidity in the effluent
6. Chemical adsorption a. Bonding b. Chemical interaction 7. Physical adsorption a. Electrostatic forces b. Electrokinetic forces c. van der Waals forces	Once a particle has been brought in contact with the surface of the filtering medium or with other particles, either one of these mechanisms, or both, may be responsible for holding it there
8. Flocculation	Large particles overtake smaller particles, join them, and form still larger particles. These particles are then removed by one or more of the above removal mechanisms (1 through 5)
9. Biological growth	Biological growth within the filter will reduce the pore volume and may enhance the removal of particles with any of the above removal mechanisms (1 through 5)

[a] Adapted from Ref. 18.

[b] Usually identified in the literature as removal mechanisms.

FILTRATION

DEEP BED FILTRATION (depth filtration)

Solids are removed within a bed of porous material

e.g. Rapid granular bed filters

CAKE FILTRATION

Particle removal occurs largely at the surface of the media through formation of a filter cake

e.g. Pre-coat filtration (diatomite , diatomaceous earth)

Slow sand filters

CLASSIFICATION OF FILTERS

1) According to type of granular medium used

→ **single medium (sand or anthracite)**

→ **dual media (anthracite and sand)**

→ **multi 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

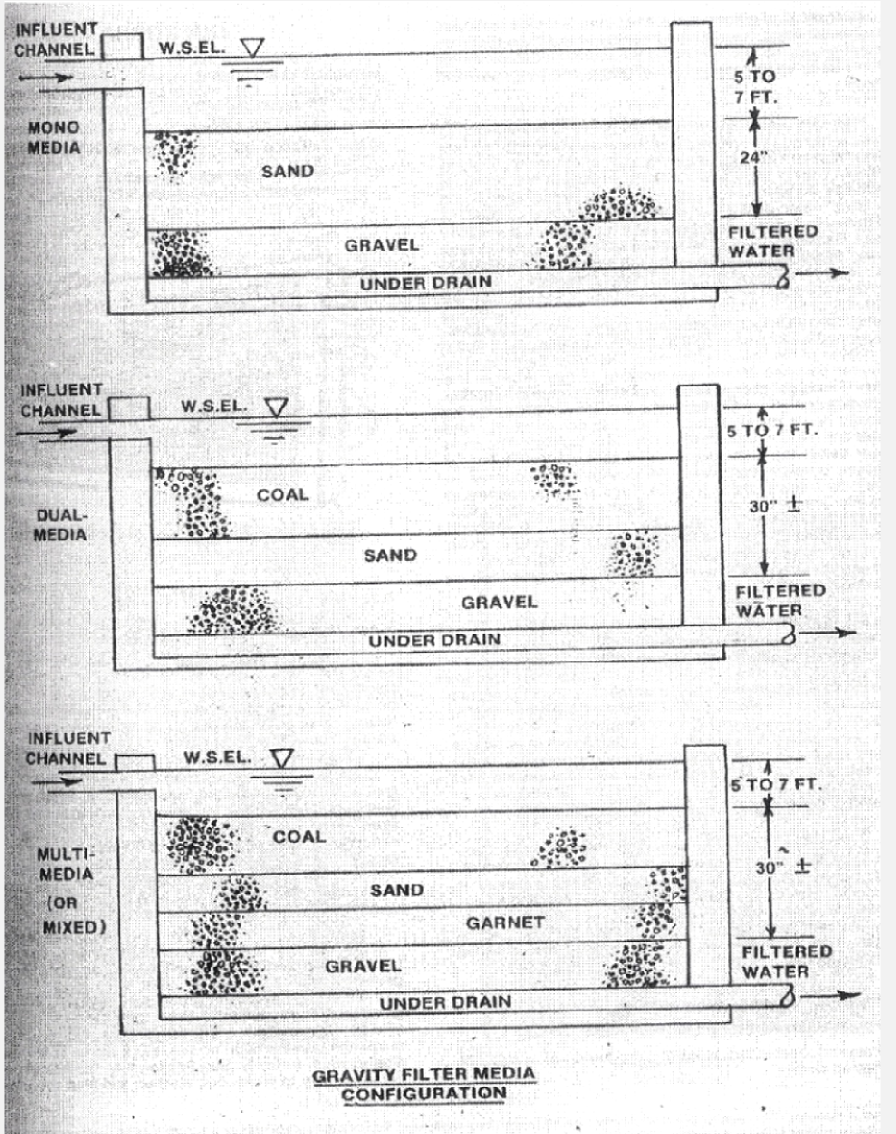


Fig. 6.6 Gravity filter media layouts

CLASSIFICATION OF FILTERS

2) According to flow through medium

→**Gravity filters**

are open to the atmosphere
Flow through the medium is achieved by gravity

→**Presure filters**

Filter medium is contained in pressure vessel
Water is delivered to the vessel under pressure

CLASSIFICATION OF FILTERS

3) According to rate of filtration

→**Rapid sand filters**

→**Slow sand filters**

3) According to filter flow control scheme

→**Constant rate** (constant head or variable head)

→**Declining rate** (constant head or variable head)

FILTER MEDIA

A number of properties of filter media are important in affecting filtration performance. These are

- → size
- → size distribution
- → slope
- → density
- → porosity

Grain size and size distribution

Grain size → principal filter medium characteristic that affects the filtration operation

It affects → clear water headloss
build – up of headloss during filter run

the smaller the size of granular media → the smaller the pore opennings through which the water must pass → small pore openings increase filtration efficiency

However;

As the size of pores ↓ Headloss through medium ↑

Large size of granular media → Pore size ↑ Headloss ↓ → However, many of the small particles in the influent will pass directly through bed.

Uniform granular media → Permit deeper penetrations of floc better utilization of the storage capacity of the bed

Moreover;
during backwashing
(cleaning of media with water in reversal direction of flow)

bed of nonuniform medium will stratify with smaller particles
→ smaller pore openings at the top

The **size of filter media** is specified by EFFECTIVE SIZE

The **uniformity of filter media** is specified by UNIFORMITY COEFFICIENT

Effective size (d_{10})
Uniformity coefficient (d_{60}/d_{10})

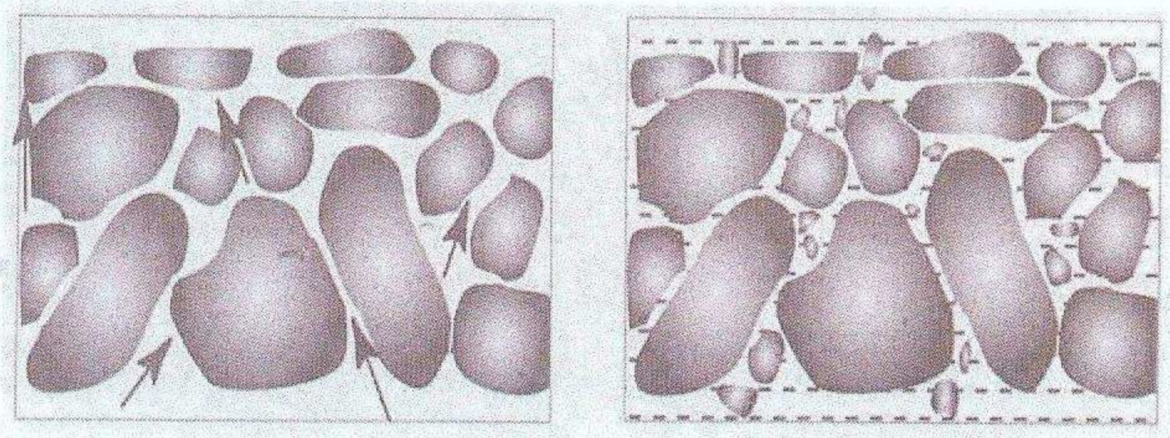
} Determined by SIEVE ANALYSIS

d_{10} (effective size) → sieve opening size in mm which permits 10% of medium by weight to pass

d_{60} → sieve opening size in mm which permits 60% of medium by weight to pass (effective size (d_{10})

As UC ↑ nonuniformity↑

Low Uc	High Uc
narrowly graded sand	widely graded sand



Large pore space allows rapid oxygen diffusion and unsaturated flow around the sand particles.	*Inclusion of small particles filling interspaces between large particles encourages clogging.*

Sieve Analysis

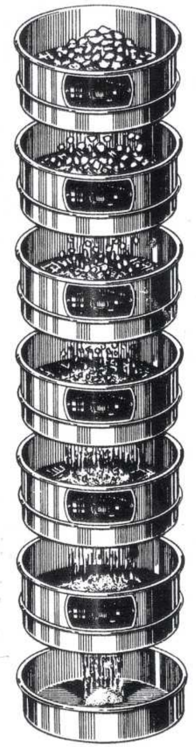


Figure 9.1. The principle of laboratory sieving with a stack o sieves. (Courtesy Tyler Industrial Products).

→ Sieve screens are placed in ascending order with the largest opening on top and the smallest opening on the bottom

→ Medium is placed on the top sieve and the stack is shaken for a prescribed amount of time

→ At the end of shaking period, the mass of material retained on each sieve is determined

→ The cumulative mass is recorded and converted into percentages by mass equal to or less than the size of seperation of the overlying sieve

→ Cumulative frequency distribution is plotted

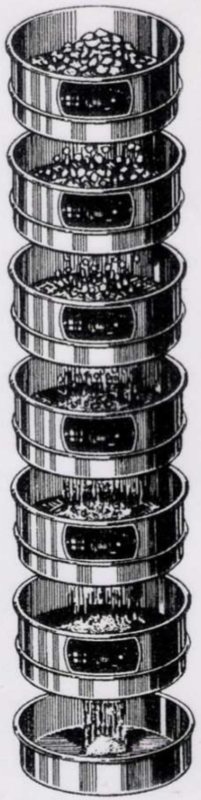


Figure 9.1. The principle of laboratory sieving with a stack of sieves. (Courtesy Tyler Industrial Products).

9.1.1. Sieve Series

The important sieve series are based as follows. (Actual apertures are given in Appendix C.)

U.S. Sieve Series. This series is based on a sieve having a 1 mm square aperture, with successive sieves now having apertures in a $\sqrt[4]{2}$ ratio. Sieves are designated by the aperture size, apertures over 1 mm being expressed in millimeters, those finer than 1 mm in micrometers (microns). The sieves also have an alternative arbitrary number designation, which although similar to the mesh count is not necessarily the same.

International Test Sieve Series. The International Standards Organization has recommended an international standard series, and the U.S. series corresponds to this. Consequently sieve analyses intended for international publication should be reported in terms of the apertures of the U.S. series.

Tyler Series. This is one of the original geometric series of sieves and is still widely used. It differs from the U.S. series in that it identifies the sieves by a mesh designation rather than aperture. The series is based on a aperture 0.0029 in. (74 μm) square and a wire diameter of 0.0021 in. (53 μm). Wire diameter plus aperture equals 0.0050 in. (127 μm) so that the sieve has 200 apertures per linear inch and is known as the 200 mesh Tyler sieve. Successive sieves have apertures with a $\sqrt{2}$ ratio, although a "double series" with $\sqrt[4]{2}$ ratios is also used.

British Standard Series. These sieves are based on wire of British Standard Gauge and are adjusted within tolerances to have apertures that are interchangeable with the other series, although again mesh designations are different.

9.1.2. Sieve Shakers

There are a number of machines available for shaking stacks of sieves, and besides taking much of the tedium out of sieving, they give more consistent results. A typical machine is shown in Fig. 9.2. In

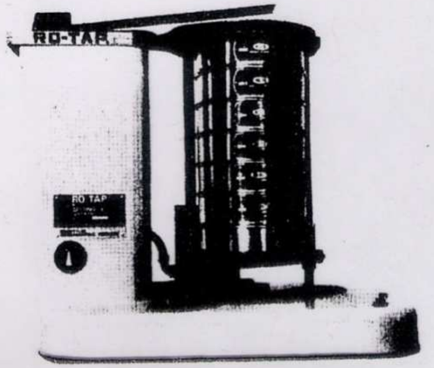


Figure 9.2. A laboratory sieve shaker. (Courtesy Tyler Industrial Products.)

EXAMPLE 1

Draw the grain size distribution curve. Determine effective size and uniformity coefficient

US Sieve No	4	10	20	40	100	200	Pan
Sieve Opening (mm)	4.75	2	0.85	0.425	0.15	0.075	
MASS RETAINED (g)	100	150	200	250	200	100	5

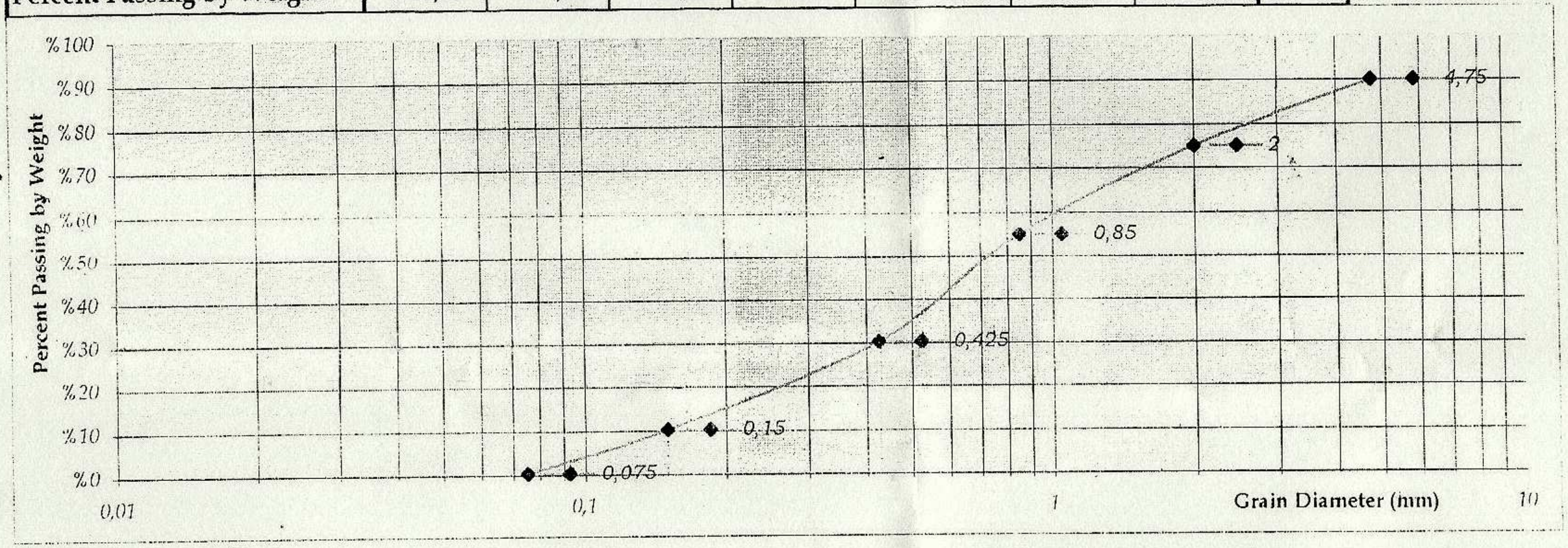
US Sieve No	Sieve Opening (mm)	Mass Retained (g)	Mass Passing (g)	Percent passing by weight	Percent retained by weight
4	4.75	100	905g	90.04	9.95
10	2.00	150	755g	75.12	24.87
20	0.85	200	555g	55.22	44.78
40	0.425	250	305g	30.34	69.65
100	0.15	200	105g	10.44	89.55
200	0.075	100	5g	0.49	99.50
PAN		5	0g	0	100

M_{total} =1005g

SIEVE ANALYSIS

*2 Values can be entered additionally by unhiding F & H columns.

US Sieve No.	4	10	20	40	100	200	Pan
Sieve Opening (mm.)	4,75	2	0,85	0,425	0,15	0,075	0
Mass Retained (gr)	100	150	200	250	200	100	5
Percent Retained by Weight	%9,95	%24,88	%44,78	%69,65	%89,55	%99,50	%100,00
Percent Passing by Weight	%90,05	%75,12	%55,22	%30,35	%10,45	%0,50	%0,00



d10= 0.15

d60= 0.03

UC= 0.03/0.15=6.86

Grain Shape

The shape of filter grains are important because it effects

→backwash flow requirement of medium

→fixed bed porosity

→headloss for flow through medium

→filtration efficiency

→the ease of sieving

Useful measure of shape → sphericity

$$\Psi = \frac{\text{surface area of sphere having same volume with particle } / V_s}{\text{surface area of particle } / V_p}$$ (Since Vs = Vp)

$$\psi = \frac{\text{surface area of sphere having same volume with particle}}{\text{surface area of particle}}$$

For a sphere--> $V_s = \frac{\pi d^3}{6}$ $A_s = \pi d^2$

For an irregular shape particle; $\Psi = \frac{\pi d^2 / \pi d^3 / 6}{A_p / V_p} \Rightarrow \frac{A_p}{V_p} = \frac{6}{\Psi d}$

Grain Density

It affect → backwash flow requirement of the medium

Porosity

$$\text{Porosity} = \frac{V_v}{V_T} \Rightarrow \text{denoted as } \%$$

As the particles become less spherical → porosity of a given volume increases

Porosity → depends on how well particles fit together

POROSITY
- → Fixed bed porosity (compacted – bed porosity)
- → Loose bed porosity

Rapid Sand Filtration

Filtration rate = 5 – 25 m^3/m^2.hr

gravity filter (typical filt. rate 8- 12 m/hr) or pressure filter (up to 25 m/hr)

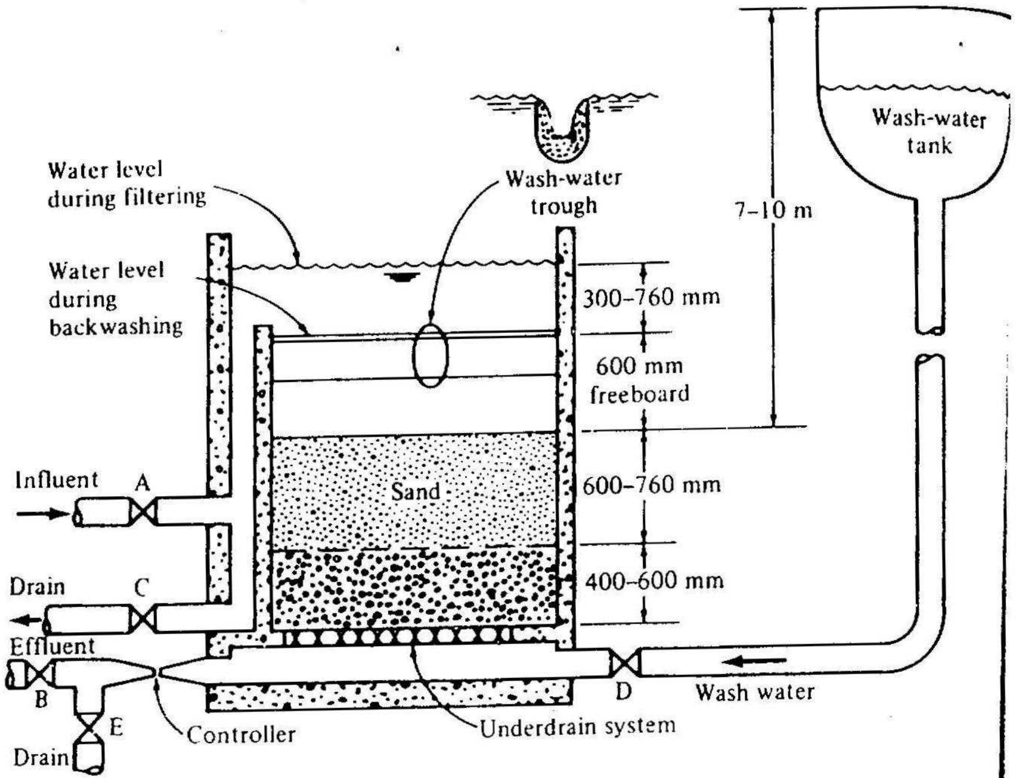
<u>During operation;</u>

solids are removed from the water and accumulate within the voids and on top surface of the filter medium

this clogging results in a gradual increase in headloss

after a period of operation, the filter is cleaned by backwashing with an upward flow of water

Operating time between backwashes → a Filter Cycle or a Filter Run
Headloss at the end of filter run→ Terminal Head Loss



How filter operates

1. Open valve A. (This allows influent to flow to filter.)
2. Open valve B. (This allows water to flow through filter.)
3. During filter operation all other valves are closed.

How filter is backwashed

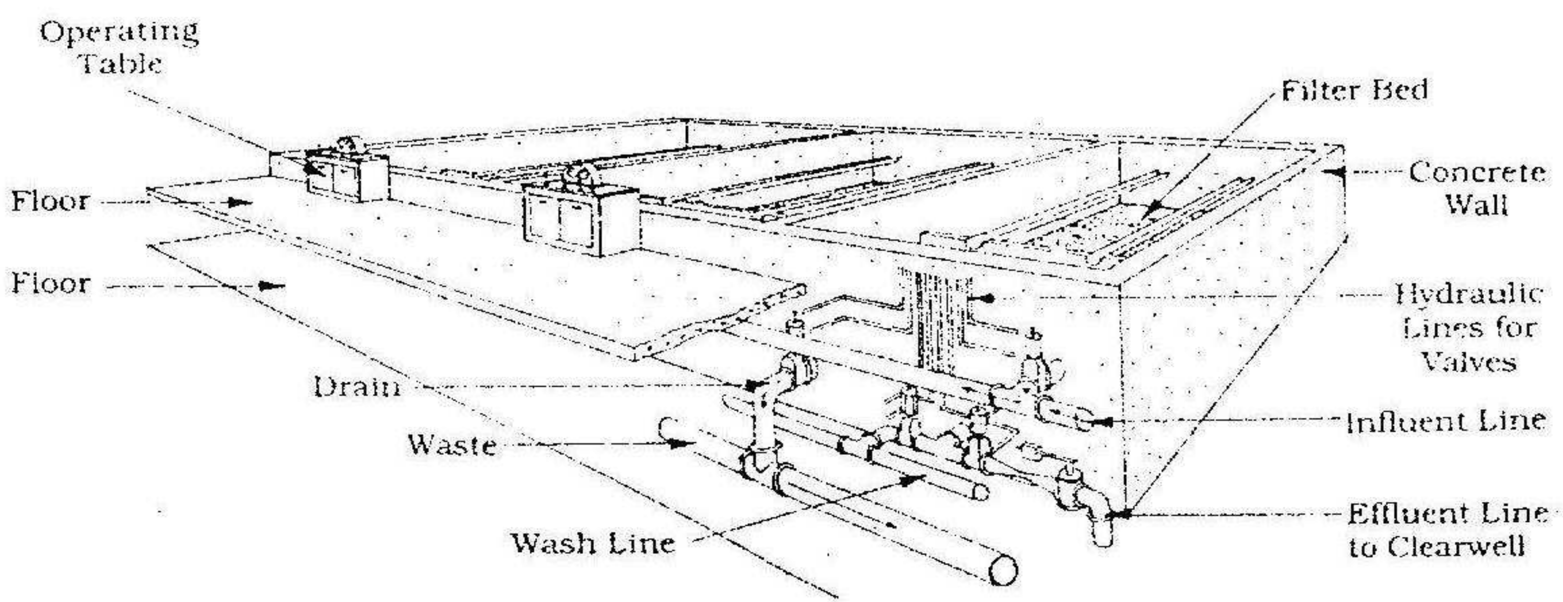
1. Close valve A.
2. Close valve B when water in filter drops down to top of overflow.
3. Open valves C and D. (This allows water from wash-water tank to flow up through the filtering medium, loosening up the sand and washing the accumulated solids from the surface of the sand, out of the filter. Filter backwash water is returned to head end of treatment plant.

How to filter to waste (if used)

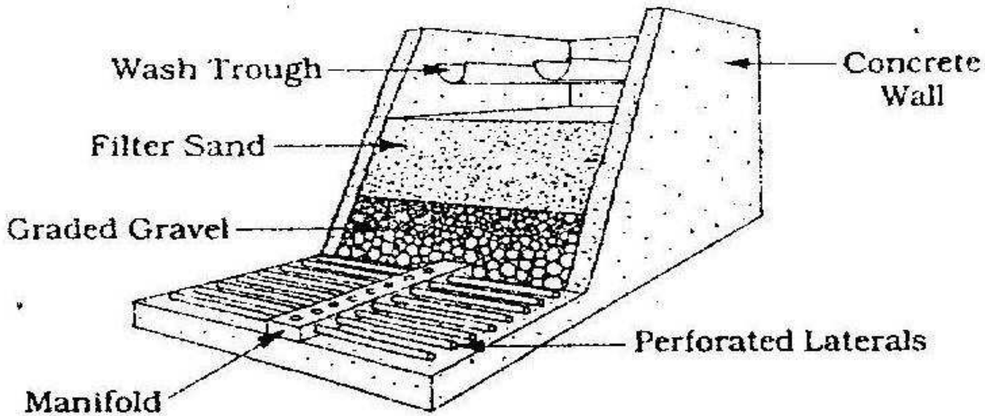
1. Open valves A and E. All other valves closed. Effluent is sometimes filtered to waste for a few minutes after filter has been washed to condition the filter before it is put into service.

Figure 4-28 Typical gravity flow filter operation. (*From Metcalf & Eddy, Inc.* [4-40].)

Figure 4.1. *Gravity Filters and Accessories*
Courtesy of the National Lime Association.



(a) Perspective of a Battery of Filters



(b) Perspective through a Filter

The design variables for rapid sand filters:

→filter media

→underdrain

→backwash arrangements

→rate control systems

Filter Media Characteristics

TABLE 8.2 Typical Grain Sizes for Different Applications (AWWA, 1990)

	Effective size, mm	Total depth, m
A. *Common U.S. Practice after Coagulation and Settling*		
1. Sand alone	0.45–0.55	0.6–0.7
2. Dual media	0.9–1.1	0.6–0.9
Add anthracite (0.1 to 0.7 of bed)		
3. Triple media	0.2–0.3	0.7–1.0
Add garnet (0.1 m)		
B. *U.S. Practice for Direct Filtration*		
Practice not well established. With seasonal diatom blooms, use coarser top size. Dual-media coal, 1.5-mm ES		
C. *U.S. Practice for Fe and Mn Filtration*		
1. Dual media similar to A-2 above		
2. Single medium	<0.8	0.6–0.9
D. *Coarse Single-Medium Filters Washed with Air and Water Simultaneously*		
1. For coagulated and settled water	0.9–1.0	0.9–1.2
2. For direct filtration	1.4–1.6	1–2
3. For Fe and Mn removal	1–2	1.5–3

TABLE 8.1 Typical Properties of Common Filter Media for Granular-Bed Filters[5,8,9] (AWWA, 1990)

	Silica sand	Anthracite coal	Granular activated carbon	Garnet	Ilmenite
Grain density, ρ_s, g/cm^3	2.65	1.45–1.73	1.3–1.5†	3.6–4.2	4.2–4.6
Loose-bed porosity ϵ_0	0.42–0.47	0.56–0.60	0.50	0.45–0.55	‡
Sphericity ψ	0.7–0.8	0.46–0.60	0.75	0.60	‡

†For virgin carbon, pores filled with water, density increases when organics are adsorbed.
‡Not available.

Filter Media Characteristics

TABLE 14.8 Design Features of Monomedium Filter Beds for Wastewater Treatment[a] (Droste, 1997)

Characteristic	Value: Range	Value: Typical
Shallow bed (stratified)		
Sand		
Depth, cm (in.)	25–30 (10–12)	28 (11)
Effective size, mm	0.35–0.6	0.45
Uniformity coefficient	1.2–1.6	1.5
Filtration rate, m/h (gal/ft^2/min)	5–15 (2–6)	7 (3)
Anthracite		
Depth, cm (in.)	30–50 (12–20)	40 (16)
Effective size, mm	0.8–1.5	1.3
Uniformity coefficient	1.3–1.8	1.6
Filtration rate, m/h (gal/ft^2/min)	5–15 (2–6)	7 (3)
Conventional (stratified)		
Sand		
Depth, cm (in.)	50–76 (20–30)	60 (24)
Effective size, mm	0.4–0.8	0.65
Uniformity coefficient	1.2–1.6	1.5
Filtration rate, m/h (gal/ft^2/min)	5–15 (2–6)	7 (3)
Anthracite		
Depth, cm (in.)	60–90 (24–36)	76 (30)
Effective size, mm	0.8–2.0	1.3
Uniformity coefficient	1.3–1.8	1.6
Filtration rate, m/h (gal/ft^2/min)	5–20 (2–8)	10 (4)
Deep bed (unstratified)		
Sand		
Depth, cm (in.)	90–180 (36–72)	120 (48)
Effective size, mm	2–3	2.5
Uniformity coefficient	1.2–1.6	1.5
Filtration rate, m/h (gal/ft^2/min)	5–24 (2–10)	12 (5)
Anthracite		
Depth, cm (in.)	90–215 (36–84)	150 (60)
Effective size, mm	2–4	2.75
Uniformity coefficient	1.3–1.8	1.6
Filtration rate, m/h (gal/ft^2/min)	5–24 (2–10)	12 (5)

[a]Metcalf and Eddy (1991), *Wastewater Engineering: Treatment, Disposal, Reuse*, 3rd ed., G. Tchobanoglous and F. L. Burton, eds., McGraw-Hill, Toronto, reproduced with permission of McGraw-Hill, Inc.

Filter Media Characteristics

TABLE 14.2 Particle Sphericity and Porosity (Droste, 1997)

Description	Sphericity (ψ)	Typical porosity (e)
Spherical	1.00	0.38
Rounded	0.98	0.38
Worn	0.94	0.39
Sharp	0.81	0.40
Angular	0.78	0.43
Crushed	0.70	0.48

TABLE 14.3 Filter Media Characteristics (Droste, 1997)

Material	Shape	Sphericity	Relative density	Porosity %	Effective size mm
Silica sand	Rounded	0.82	2.65	42	0.4–1.0
Silica sand	Angular	0.73	2.65	53	0.4–1.0
Ottawa sand	Spherical	0.95	2.65	40	0.4–1.0
Silica gravel	Rounded		2.65	40	1.0–50
Garnet			3.1–4.3		0.2–0.4
Crushed anthracite	Angular	0.72	1.50–1.75	55	0.4–1.4
Plastic		Any characteristics of choice			

Filter Media Characteristics

TABLE 12.7

Typical Design Data for Granular-Medium Filters Used for the Treatment of Wastewater (Schroeder, 1985)

PARAMETER*	SINGLE MEDIUM† Range	SINGLE MEDIUM† Typical	SINGLE MEDIUM‡ Range	SINGLE MEDIUM‡ Typical	DUAL MEDIUM Range	DUAL MEDIUM Typical
Sand						
Depth, mm	200–300	250	500–900	600	150–300	300
Effective size, mm	0.4–0.6	0.45	0.45–0.7	0.5	0.4–0.7	0.55
Uniformity coefficient	1.3–1.7	1.5	1.3–1.7	1.5	1.4–1.7	1.6
Anthracite						
Depth, mm			900–1800	1500	300–600	500
Effective size, mm			0.8–1.8	1.4	0.8–1.8	1.2
Uniformity coefficient			1.4–1.8	1.6	1.4–1.8	1.6
Filtration rate, $L/m^2 \cdot min$	80–320	160	80–400	160	80–400	160
Backwashing	Air pulse followed by water, chemical cleaning		Air/water, surface wash		Air/water, surface wash	
Backwash rate, $L/m^2 \cdot m$	360–800	600	360–1000§	500§	500–1600	800

*The effective size is defined as the 10 percent size by mass, d_{10}. The uniformity coefficient is defined as the ratio of the 60 to the 10 percent size by mass ($UC = d_{60}/d_{10}$).

†Pulsed-bed filter.

‡Separate sand and anthracite single-medium filters.

§For single medium sand filter only

Filter Media Characteristics

TABLE 12.6

Typical Design Data for Granular-Medium Filters Used for the Treatment of Water (Schroede

PARAMETER*	SINGLE MEDIUM†		DUAL MEDIUM		MULTIMEDIUM	
	Range	Typical	Range	Typical	Range	Typical
Garnet or ilmenite						
Depth, mm					75–200	100
Effective size, mm					0.2–0.35	0.25
Uniformity coefficient					1.3–1.7	1.6
Sand						
Depth, mm	500–900	600	150–500	300	150–400	300
Effective size, mm	0.35–0.70	0.45	0.45–0.6	0.5	0.45–0.6	0.5
Uniformity coefficient	1.3–1.7	1.5	1.4–1.7	1.6	1.4–1.7	1.6
Anthracite						
Depth, mm	900–1800	1500	400–600	500	400–600	500
Effective size, mm	0.7–1.0	0.75	0.8–1.4	1.0	0.8–1.4	1.1
Uniformity coefficient	1.4–1.8	1.6	1.4–1.8	1.6	1.4–1.8	1.6
Filtration rate, $L/m^2 \cdot min$	80–400	160	80–400	160	80–400	160
Backwashing	Air/water, surface wash		Air/water, surface wash		Air/water, surface wash	
Backwash rate, $L/m^2 \cdot min$	360–1000‡	500‡	500–1600	800	500–1600	800

*The effective size is defined as the 10 percent size by mass, d_{10}. The uniformity coefficient is defined as the ratio of the 60 to the 10 percent size by mass ($UC = d_{60}/d_{10}$).

†Separate sand and anthracite single-medium filters.

‡For single medium sand filter only

Filter Media Characteristics

. Değişik tatbikatlar için dane boyutları ve yatak kalınlıkları (EROĞLU, 1984)

a) Amerikan Tatbikatı

Yumaklaştırma ve çöktürmeden sonraki içme suyu tasfiyesi için :

	Dane çapı (mm)	Toplam yatak derinliği (m)
1. Sadece kum yatak	0.5–1.2	0.6–0.7
2. Çift malzemeli yatak çok kullanılır. (Yatağın 0.1–0.7 si antrasit)	0.9–2.5	0.6–0.9
3. Üç malzemeli yatak (0.1 m çakıl eklenir)	0.25–0.75	0.7–1.0

Amerikan tatbikatında ham su için doğrudan filtrasyon nadir olarak kullanılmaktadır.

b) İngiliz Tatbikatı

		Dane çapı (mm)	Toplam yatak derinliği (m)
1. Sadece kum yatak (çok kullanılır)			
Yumaklaştırma ve çökeltmeden sonra		0.6–1.2	0.7
Yavaş kum filtrelerinden önce (ham su)		0.7–2.0	–
2. Çift malzeme (son zamanlarda tatbik ediliyor)			
İri daneli kömür ve kum	Kömür	1.2–2.5	0.7
	Kum	0.6–1.2	

Filter Media Characteristics

C) Avrupa Tatbikatı

	Dane çapı (mm)	Yatak derinliği (m)
1. Sadece kum kullanılması (çok tatbik edilir)		
-Yumaklaştırma ve çökeltmeden sonra	0.9-1.5	0.9-1.2
-Ham su filtrasyonu	1.0-1.5	0.8-1.2
-Ham su filtrasyonu	1.4-2.0	0.8-1.2
-Demir ve mangan giderilmesi	1-2	1.5-3
-Demir ve mangan giderilmesi	2-3	1.5-3

2. Çift malzeme (son zamanlarda yüzey sularının tasfiye işleminde kullanılmaya başlanmıştır).

		Dane çapı (mm)	Yatak derinliği (m)
- Yumaklaştırma ve çökeltmeden sonra	Kömür	1.5-2.5	1,5 - 2
	Kum	0.8-1.2	

Filter Media Characteristics

Table 4.3. Single-Medium Filter Characteristics for Water Treatment (Reynolds, 1982)

Characteristic	Value: Range	Value: Typical
Sand Medium:		
Depth, in.	24–30	27
Effective size, mm	0.35–0.70	0.60
Uniformity coefficient	<1.7	<1.7
Filtration rate, gpm/ft^2	2–5	4
Anthracite Medium:		
Depth, in.	24–30	27
Effective size, mm	0.70–0.75	0.75
Uniformity coefficient	<1.75	<1.75
Filtration rate, gpm/ft^2	2–5	4

Table 4.4. Dual-Media Filter Characteristics for Water Treatment (Reynolds, 1982)

Characteristic	Value: Range	Value: Typical
Anthracite:		
Depth, in.	18–24	24
Effective size, mm	0.9–1.1	1.0
Uniformity coefficient	1.6–1.8	1.7
Sand:		
Depth, in.	6–8	6
Effective size, mm	0.45–0.55	0.5
Uniformity coefficient	1.5–1.7	1.6
Filtration rate, gpm/ft^2	3–8	5

Filter Media Characteristics

Table 4.5. Mixed-Media Filter Characteristics for Water Treatment

Characteristic	Value	
	Range	Typical
Anthracite:		
Depth, in.	16.5–21	18
Effective size, mm	0.95–1.0	1.00
Uniformity coefficient	1.55–1.75	<1.75
Sand:		
Depth, in.	6–9	9
Effective size, mm	0.45–0.55	0.50
Uniformity coefficient	1.5–1.65	1.60
Garnet:		
Depth, in.	3–4.5	3
Effective size, mm	0.20–0.35	0.20
Uniformity coefficient	1.6–2.0	<1.6
Filtration rate, gpm/ft^2	4–10	6

Filter Media Characteristics

Table 4.6. Dual-Media Filter Characteristics for Advanced or Tertiary Wastewater Treatment (Reynolds, 1982)

Characteristic	Value	
	Range	Typical
Anthracite:		
Depth, in.	12–24	18
Effective size, mm	0.8–2.0	1.2
Uniformity coefficient	1.3–1.8	1.6
Sand:		
Depth, in.	6–12	12
Effective size, mm	0.4–0.8	0.55
Uniformity coefficient	1.2–1.6	1.5
Filtration rate, gpm/ft^2	2–10	5

Filter Media Characteristics

Table 4.7. Multimedia or Mixed-Media Filter Characteristics for Advanced or Tertiary Wastewater Treatment

Characteristic	Value	
	Range	Typical
Anthracite:		
Depth, in.	8–20	16
Effective size, mm	1.0–2.0	1.4
Uniformity coefficient	1.4–1.8	1.5
Sand:		
Depth, in.	8–16	10
Effective size, mm	0.4–0.8	0.5
Uniformity coefficient	1.3–1.8	1.6
Garnet:		
Depth, in.	2–6	4
Effective size, mm	0.2–0.6	0.3
Uniformity coefficient	1.5–1.8	1.6
Filtration rate, gpm/ft^2	2–10	5

Tables 4.6 and 4.7 adapted from *Wastewater Engineering, Treatment, Disposal and Reuse* by Metcalf and Eddy, Inc.

Underdrain System

→ supports the sand

collects the filtered water

distributes the backwash water

Types:

→ Manifold with perforated lateral pipes

→ Fabricated self-supporting underdrain systems

→ False-floor underdrain with nozzles

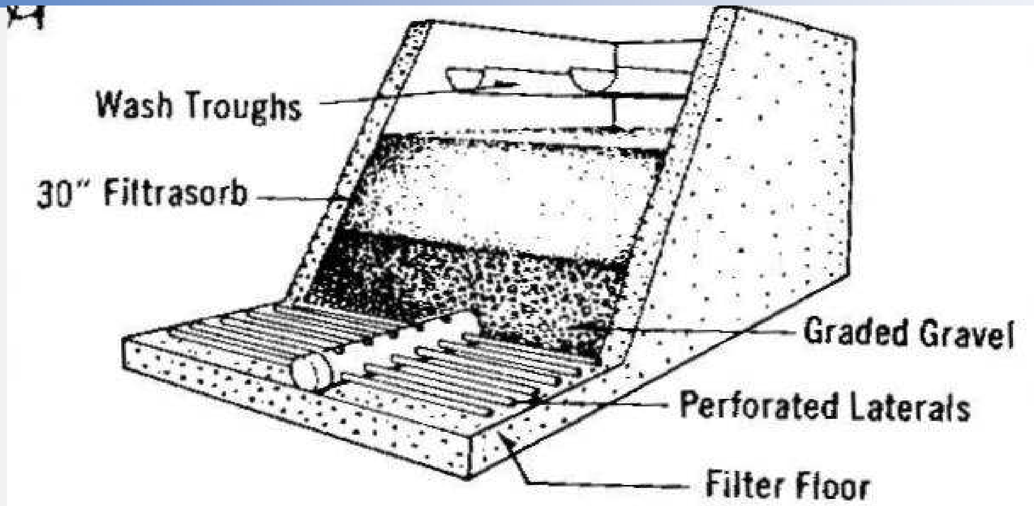


Figure 8.6 Rapid gravity filter with manifold and lateral underdrain system. (*After C. P. Hoover, Water Supply & Treatment, National Lime Assoc.*)

Manifold with perforated pipe laterals

→oldest type

→perforated pipe laterals are located at frequent intervals along manifold

→perforation in laterals (6-13 mm) located 8-30 cm spacing (Ref: AWWA, 1990)

Openings of underdrain system is larger than the filter medium to be supported

to prevent the medium from leaking downward into the underdrain system, several layers

of graded gravel between the underdrain openings and filter medium is necessary

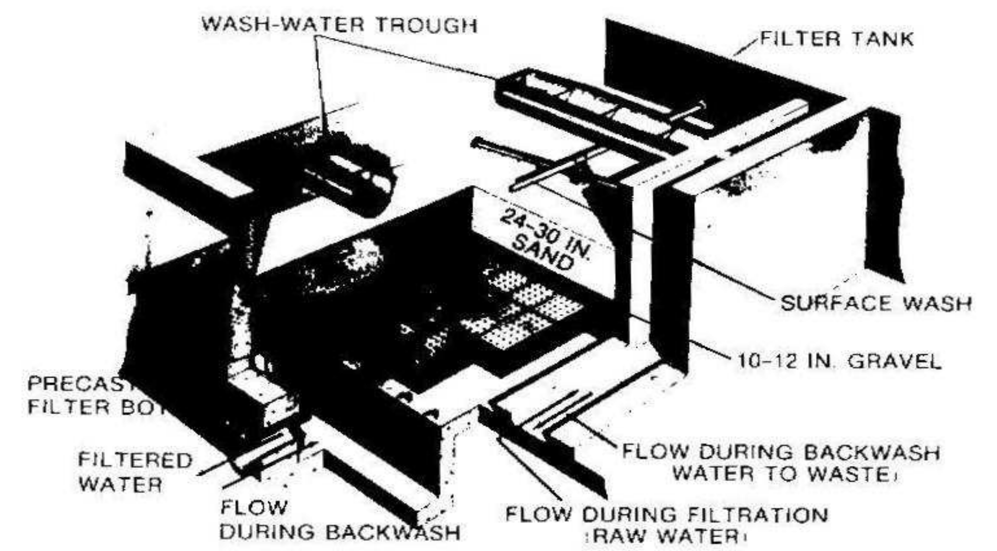


Figure 8.1 A rapid sand filtration system. (*Courtesy of F. B. Leopold*

Fabricated self-supporting underdrain systems

grouted to the filter floor

top openings are about 6 mm

False-floor underdrain with nozzles

a false-floor slab is located 0,3 –0,6 m above the bottom of filter, thus providing an underdrain plenum below the false floor

nozzles to collect the filtrate and distribute the backwash water are located at 3-20 cm centers

openings of nozzles → may be coarse (about 6 mm)

→may be very fine (sufficiently small to retain the filter medium)

usually gravel layer is not required for this type of underdrain system

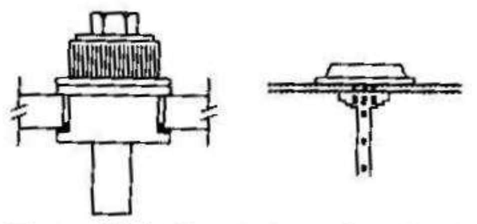
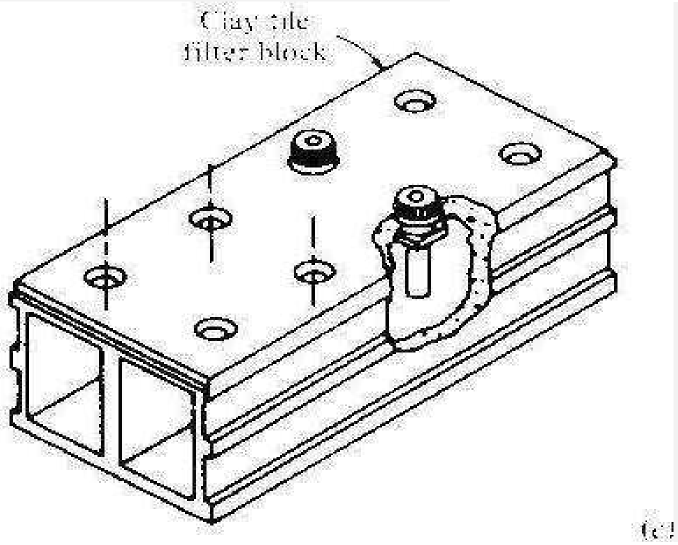
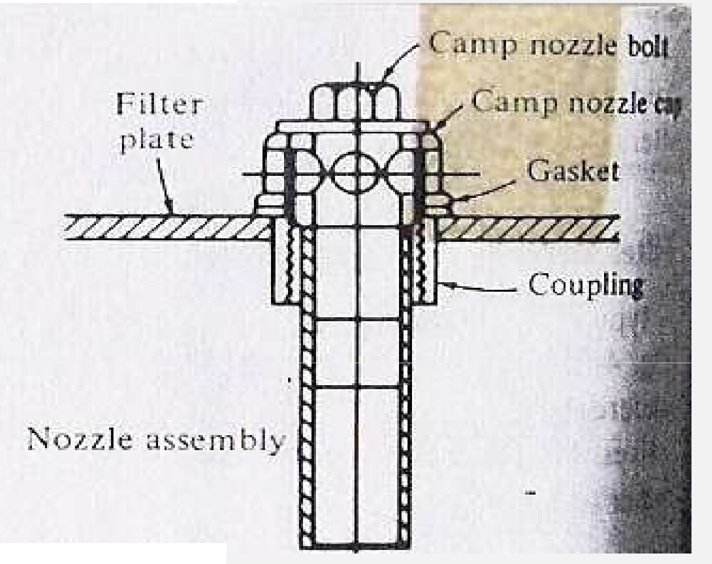


Figure 14.8 Strainers used in false-bottom underdrains without gravel.





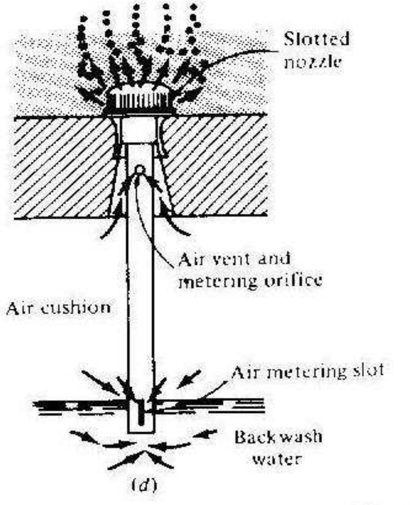


Figure 4-29 Proprietary filter underdrains: (a) BIF, Unit of General Signal Corp.; (b) F.

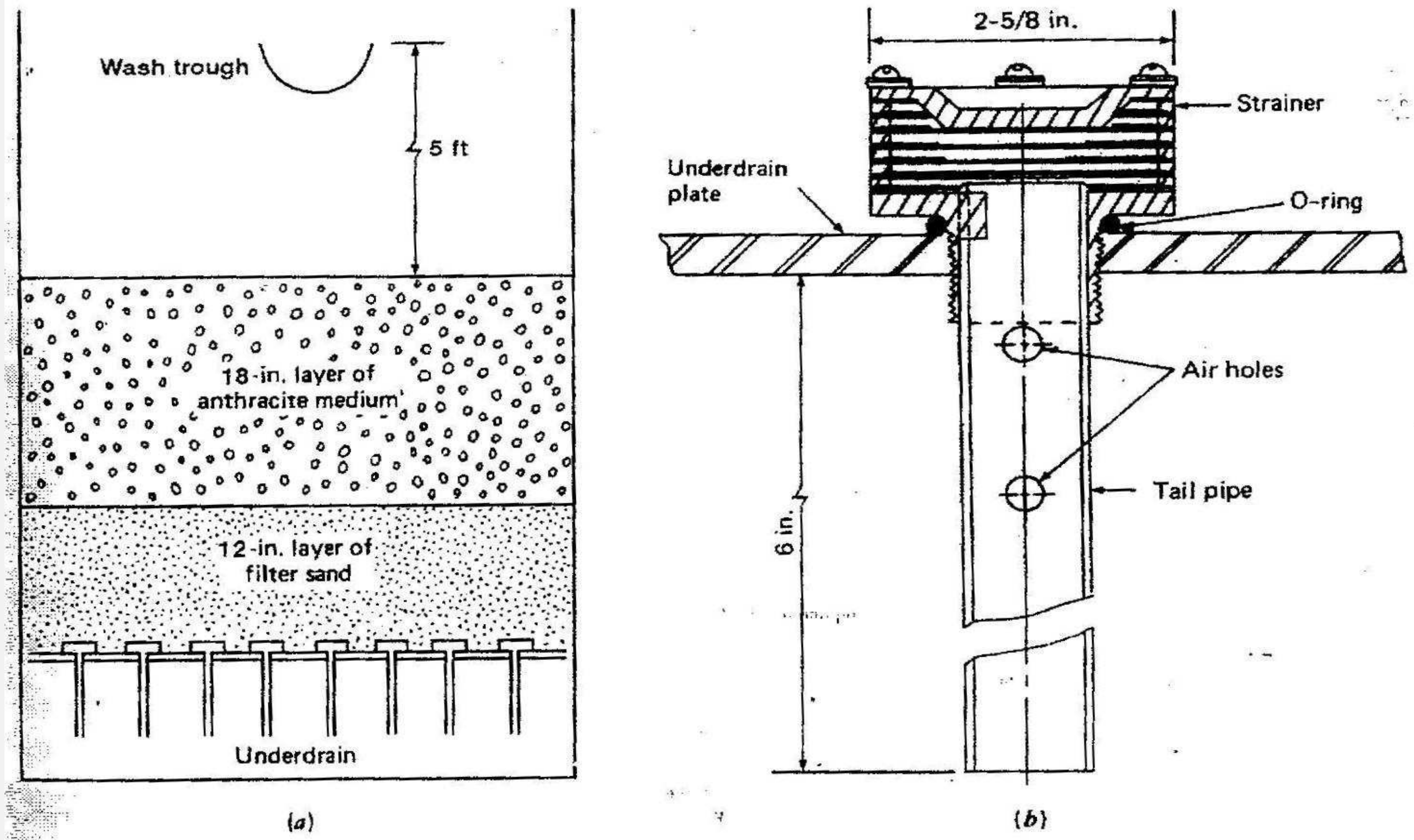


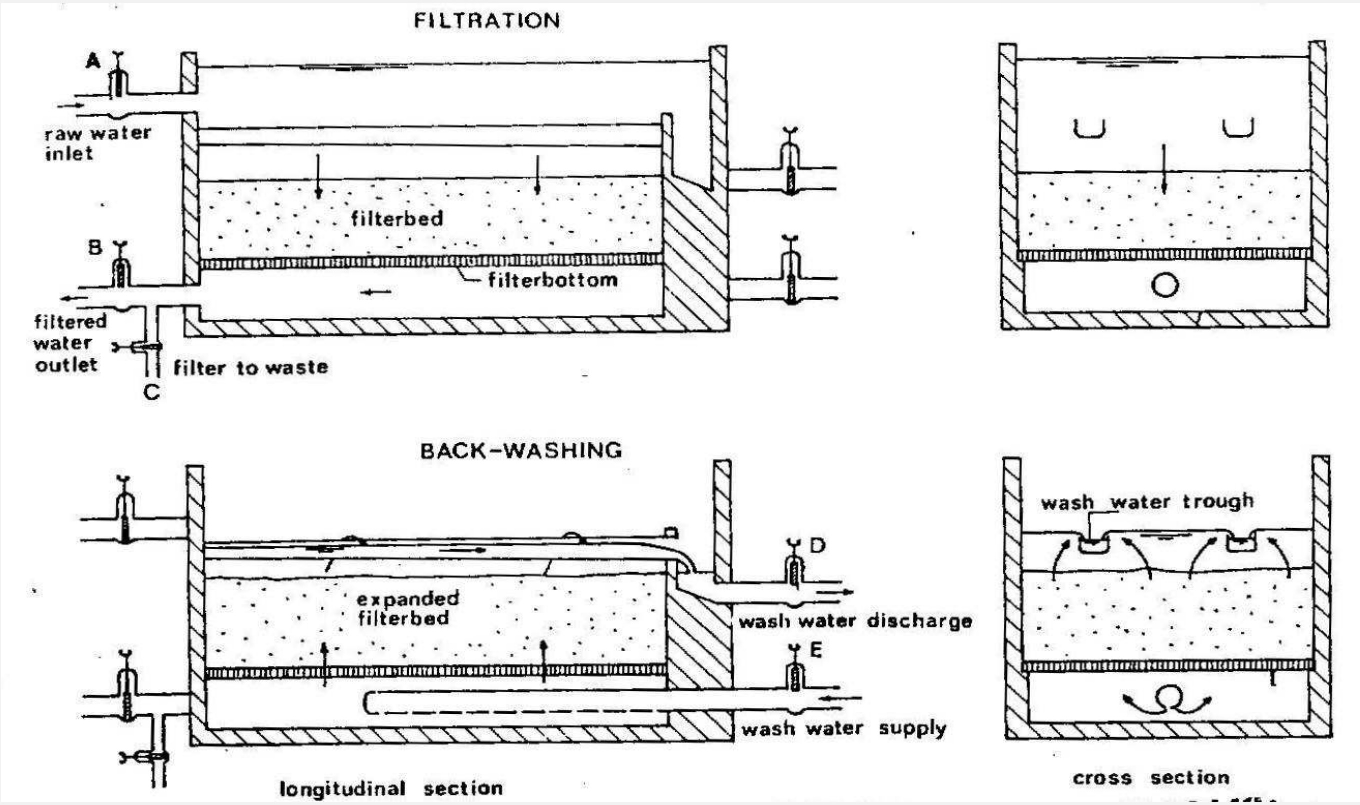
Figure 7-15 Underdrain system for air scouring and water backwashing of a granular-media filter. (*a*) Cross section of the filter. (*b*) Detail of the air-water nozzle. (Courtesy of General Filter Co., Ames, IA.)

Headloss calculation through the underdrain openings

Orifice Equation à Headloss = $C_d V^2/(2g)$ where C_d = discharge coeff. for the orifice

Backwash Arrangements

Purpose of backwashing: a to remove suspended material that has been deposited in the filter bed during the filter cycle



Need for backwash is indicated by one of the following three criteria:

Increase of headloss across the filter to the available limit or to a lower established limit

Deterioration of filtered water quality

Maximum time limit

The methods used for backwashing granular medium filter beds:

water backwash with full fluidization

surface wash plus fluidized bed backwash

air scour-assisted backwash

The amount of water required for backwash

The washwater may be supplied :

by a pump which pumps directly from clear well

by an elevated storage tank

Volume of washwater = 1 – 5% of water filtered

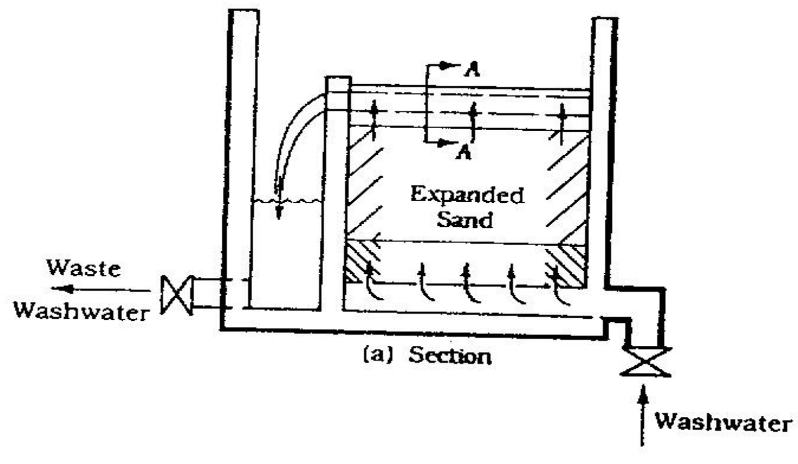
Collection of washwater

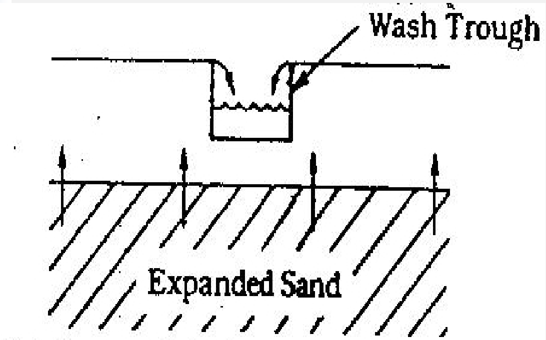
Washwater may be collected and removed from the filter by :

a system of troughs and gullets (used extensively in U.S design)

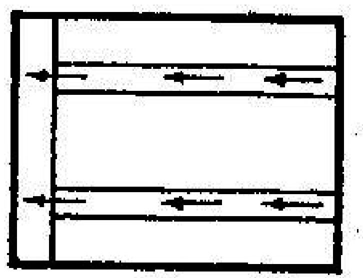
only gullets (used in European design)

Figure 4.15. Schematic Showing Filter during Backwashing





(b) Section A-A through Wash Trough



(c) Washwater Flow

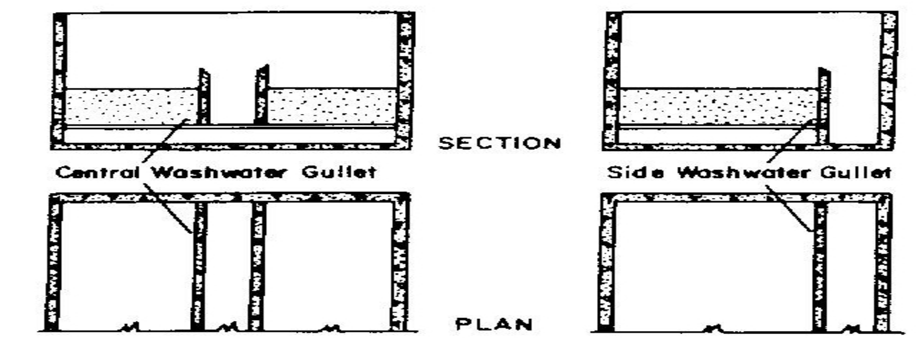


Figure 8.12. Arrangements for washwater gullets. *Source:* Arboleda, 1973.

Water backwash with full fluidization

backwash water is introduced into the bottom of the bed through underdrain system

backwash water should be turned on gradually to avoid disturbing the gravel layers or subjecting the underdrain to sudden momentary pressure increase

the backwash flow is continued with full fluidization until the waste wash water is reasonably clear

Typical backwash rate = 37 – 49 m/hr (in US practice)
Resulting bed expansion = 15-30%

is a weak washing method
usually assisted by an auxiliary scour system such as surface wash or air scour

Surface wash plus fluidized bed backwash

surface wash systems inject jets of water from orifices located about 2.5 – 5 cm above the fixed-bed surface

surface wash operates 1- 2 min before the upflow wash

usually is continued during upflow wash

is terminated 2 to 3 min before the end of the upflow wash

Air scour-assisted backwash

air scour systems supply air to the full filter area from orifices located under the filter medium

may be applied before the water backwash
or
may be applied simultenously with water backwash

In the case when air scour is used before water backwash;

When the air scour is started, the water level will rise because of the volume occupied by the air

air scour period= 2 – 5 min

After the air scour is terminated, the water backwash starts to slowly expel the air from the bed before overflow begins

The water backwash is then continued alone with full bed fluidization until the wash water is reasonably clear.

In the case when air scour is used for a portion of water backwash;

Air alone is applied first

Then, low rate of water backwash is added below the rate of full bed fluidization

Combined air-water backwash is continued only until the water level is about 15 cm below the wash water overflow. At that level, the air flow must be terminated so that all air escapes from the bed before overflow commences

The water backwash is then continued alone with full bed fluidization until the wash water is reasonably clear.

In the case when air scour and water backwash are used simultaneously;

- the water rate is well below the fluidization velocity

- after about 10 min of simultaneous air plus water backwash, the air flow is terminated, and the water continues to expel some of the air from the bed and to flush the remaining dirt from the water above the filter medium

During this terminal water backwash period, the flowrate may be increased but remains below the full-bed fluidization velocity.

- This method of washing is very effective even though the bed is never fluidized

TABLE 11-8

Air and water backwash rates used with single-medium sand and anthracite filters[a] (Metcalf & Eddy, 1991)

Medium	Medium characteristics: Effective size, mm	Medium characteristics: Uniformity coefficient	Backwash rate: Water, gal/ft^2 · min	Backwash rate: Air, ft^3/ft^2 · min[b]
Sand	1.00	1.40	10	43
	1.49	1.40	15	65
	2.19	1.30	20	86
Anthracite	1.10	1.73	7	22
	1.34	1.49	10	43
	2.00	1.53	15	65

[a] Adapted in part from Ref. 10.

[b] Air at 70°F (21°C) and 1.0 atm.

Note: gal/ft^2 · min × 0.04075 = m^3/m^2 · min
ft^3/ft^2 · min × 0.3048 = m^3/m^2 · min

TABLE 11-7

Typical backwash flowrates required to fluidize various filter beds[a] (Metcalf Eddy, 1991)

Type of filter	Size of critical granular medium	Minimum backwash velocity needed to fluidize bed[b]: gal/ft^2 · min	Minimum backwash velocity needed to fluidize bed[b]: ft/min
Single-medium (sand)	2 mm	44–48	6–6.5
Dual-media (anthracite and sand)	See Table 11-6	20–30	2.5–4
Tri-media (anthracite, sand, and garnet or ilmenite)	See Table 11-6	20–30	2.5–4

[a] Adapted in part from Refs. 10, 32, and 35.

[b] Varies with size, shape, and specific gravity of the medium and the temperature of the backwash water.

Note: gal/ft^2 · min × 0.04075 = m^3/m^2 · min
ft/min × 0.3048 = m/min

TABLE 21-12. Typical Design Criteria for Various Backwash Systems (Montgomery, 1985)

	Fixed-Jet-Type Surface Wash	Rotary-Jet-Type Surface Wash	Air Scour Type
Pressure at discharge point			
kPa	100–200	420–680	28–50
kg/cm^2	1–2	4.2–6.8	0.28–0.5
psi	15–30	60–100	4–7
Flowrate			
Water			
$m^3/m^2 \cdot min$	0.12–0.17	0.03–0.06	0
gpm/ft^2	2.9–4.1	0.7–1.5	0
Air			
$m^3/m^2 \cdot min$	0	0	0.5–1.3
cfm/ft^2	0	0	1.5–3.5
Duration of washing, min	4–8	4–8	8–15
Backwash rate			
$m^3/m^2 \cdot min$	0.55–1.0	0.55–1.0	0.25–0.70
gpm/ft^2	13.5–22.5	13.5–22.5	6–17

. Geri Yıkama Usûlleri (Eroğlu, 1984)

Çeşitli tatbikatlar için geri yıkama usûlleri aşağıda verilmiştir.

Tatbikat	A.B.D	İngiltere	Avrupa
-Geri yıkama usûlü	Su	Önce hava sonra su	Önce hava ve su, sonra su
-Yatağın, akışkan yatak hâline getirilip getirilmediği	Evet	Sınırda	Hayır
-Yatak genişlemesi %	20-50	< 10	-
-Yatağın üstünde yıkama sistemi kullanılıp kullanılmadığı	Evet	Hayır	Hayır
-Su taşma mesafesi (m)	0.7-1	0.1-0.2	0.5

. Geri Yıkama Hızları (Eroğlu, 1984)

Çeşitli ülkelerde kum filtreler için tatbik edilen geri yıkama hızları aşağıda verilmiştir.

Tatbikat	Dane çapı mm	Sıra	Hava debisi (m/st)	Su debisi (m/st)
A.B.D.	0.5-1.2	Önce hava sonra su	54-90	36-54
İngiltere	0.6-1.2	Önce hava sonra su	18-29	13-18
Avrupa	1.0-2.0	Önce hava ve su sonra su	54-90	13-36
	2.0-3.0	Önce hava ve su sonra su	108-144	14-36
	2.0-4.0	Önce hava ve su sonra su	108-144	14-36

Geri yıkama usülü	A.B.D	İngiltere	Avrupa
Yıkama Şekli	Su	Önce hava sonra su	Hava su beraber
-Su hızı (masrafı)	Fazla	Az	Az
-Hava hızı	Kullanıl-maz	Az	Fazla
-Yıkamanın Tesirliliği	Zayıf	Orta	İyi
-Geri yıkama suyu ile Katı maddelerin taşınması	Orta	Zayıf	İyi
-Filtre tabanı altına çakıl Yerleştirmek suretiyle yapılan drenaj sistemine uygun olup olmadığı	Evet	Evet	Hayır
-İnce malzeme için uygun olup olmadığı	Evet	Evet	Hayır
-Çift malzemeli filtreler için uygun olup olmadığı	Evet	Evet*	Hayır
-Malzeme kaybı	–	Az	Çok

* Şayet yeteri kadar geri yıkama hızı ve geri yıkama suyu taşma

FILTER RATE CONTROL SYSTEMS

CONSTANT RATE FILTRATION

DECLINING RATE FILTRATION

A) CONSTANT RATE FILTRATION

holds the filtration rate constant throughout the filter run

two sub-modes → conconstant head
→ variable head

Constant Rate – Variable Head:

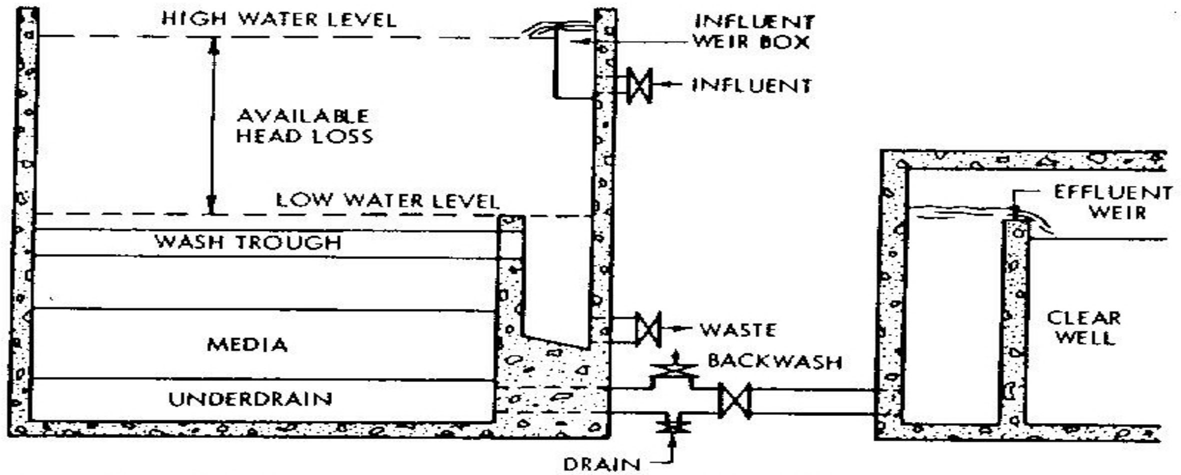


Figure 4–3 Gravity filter arrangement for rate control by influent flow splitting.

Influent flow is splitted by means of an influent weir box or orifice above the maximum water level of filter → each filter receives an equal (or nearly equal) portion of total flow

to keep the water level at the start of the filter run above the filter medium → Outlet control weir is located above the sand level

Constant Rate – Variable Head:

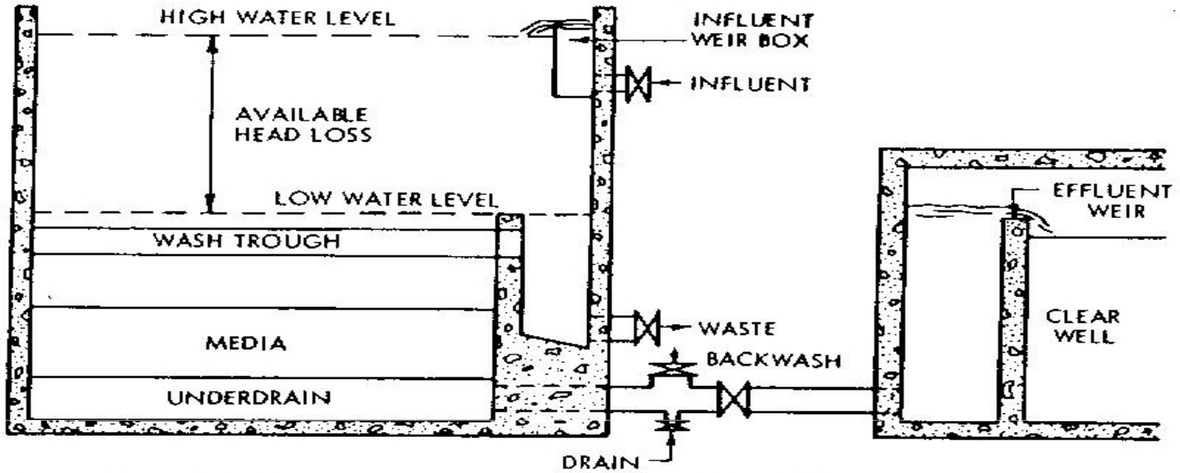


Figure 4–3 Gravity filter arrangement for rate control by influent flow splitting.

at the start of filter run → water level in the filter box is just sufficient to overcome clean filter headlosses and all other losses between the filter and filter outlet control weir

during filtration → the water level in each filter unit will rise to compensate for the headloss build up in filter bed as a result of clogging

Constant Rate – Variable Head:

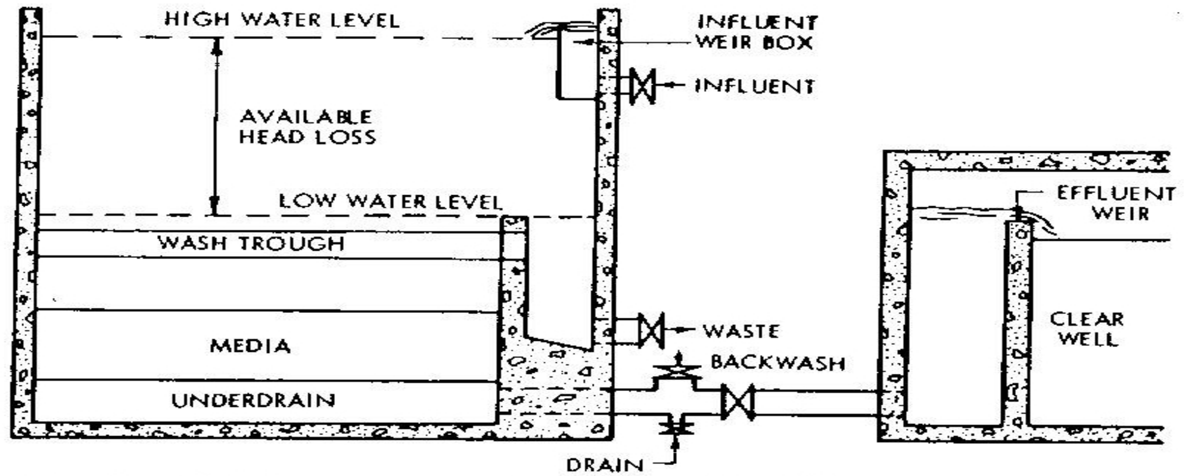
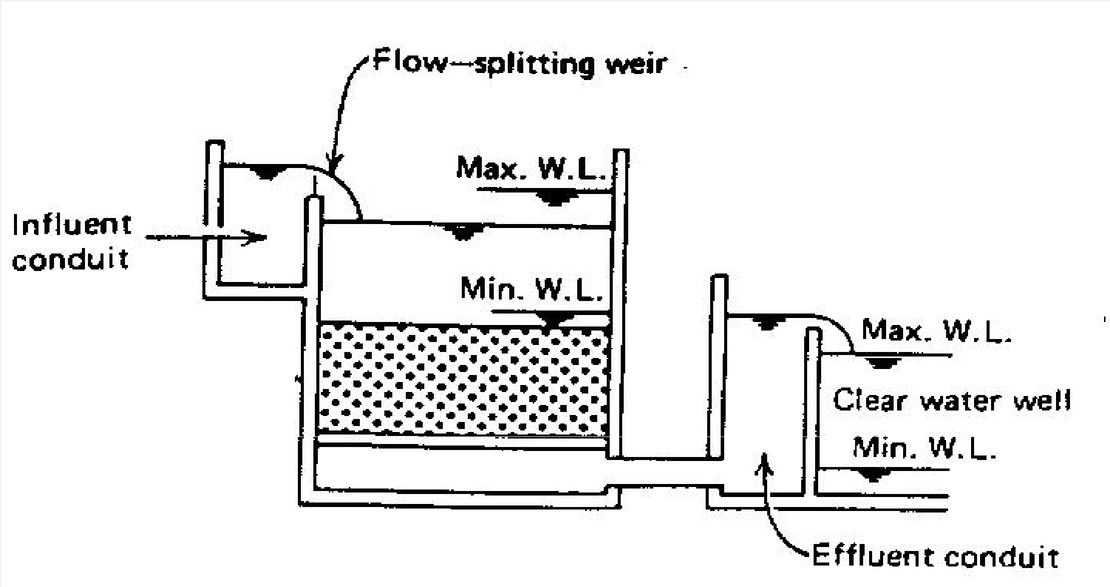


Figure 4–3 Gravity filter arrangement for rate control by influent flow splitting.

when the water surface reaches the max. permissible level above the filter bed → filter is taken out of service for backwashing

Constant Rate – Variable Head:

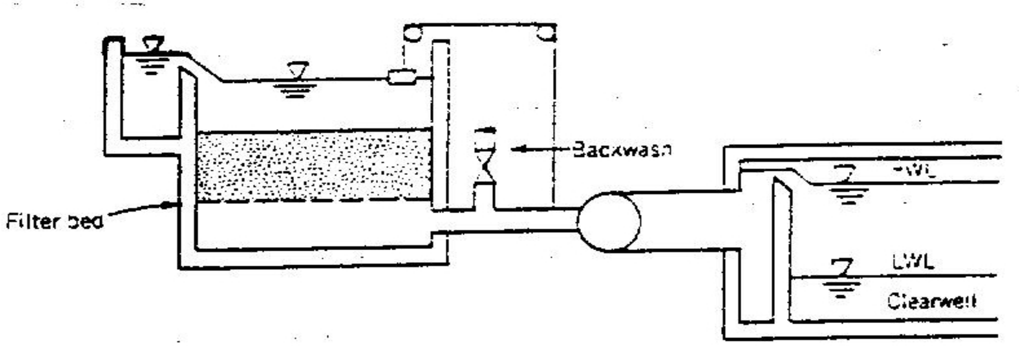


deeper

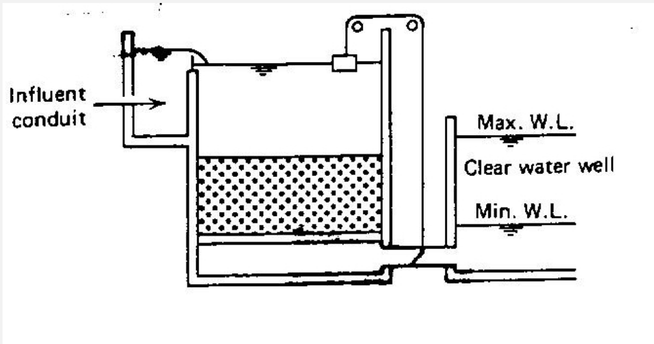
DISADVANTAGE:

considerable variations of water level in the filters → filter box must be deeper

Constant Rate –Constant Head:



Constant Level Filtration
(Influent control, level sensor & modulating valve)

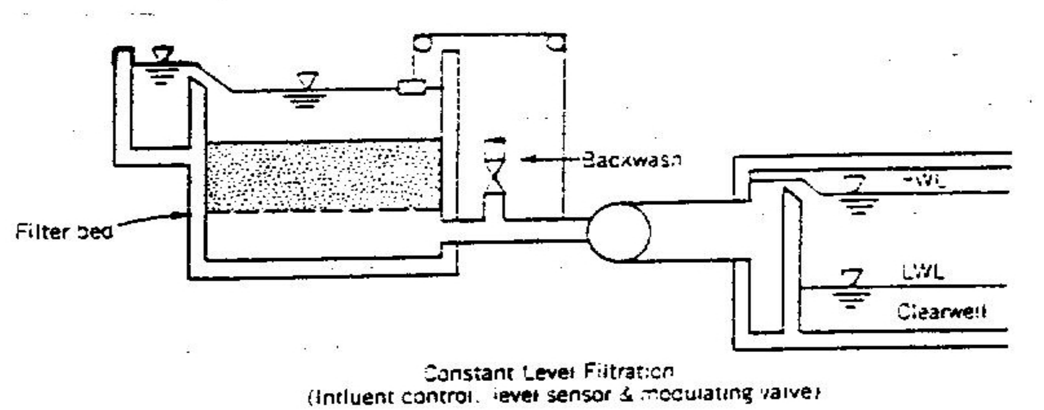


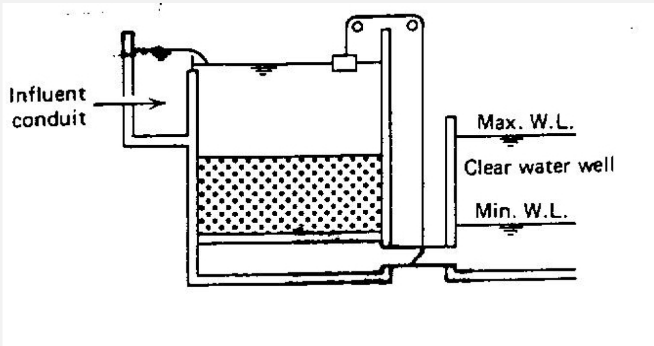
Influent flow is splitted by means of an influent weir box or orifice above the maximum water level of filter → each filter receives an equal (or nearly equal) portion of total flow

to maintain the water level above the filter bed at nearly constant level → a flow control valve (e.g butterfly valve)is placed to each filter effluent pipe

a level sensor in each filter sends a signal to control valve which opens or closes to maintain constant head

Constant Rate –Constant Head:





When the filter is first placed in operation after backwashing → the water surface will tend to drop , causing the butterfly valve to close

As the filter headloss builds up → the water level above te filter media will tend to rise, causing the valve to open

When the valve becomes wide open → valve can no longer control the water surface in filter It is time to backwash the filter

B) DECLINING RATE FILTRATION

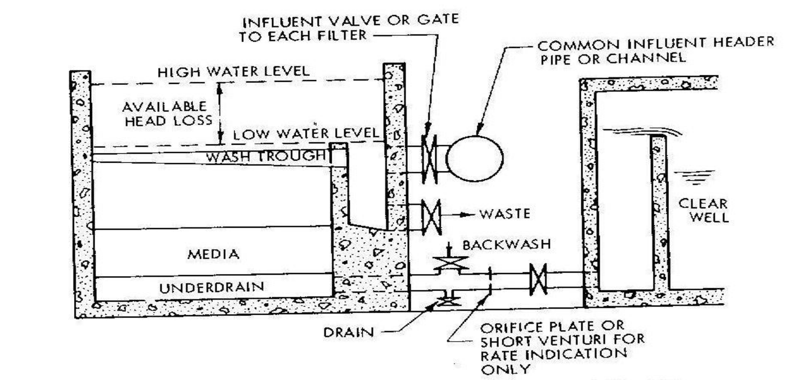
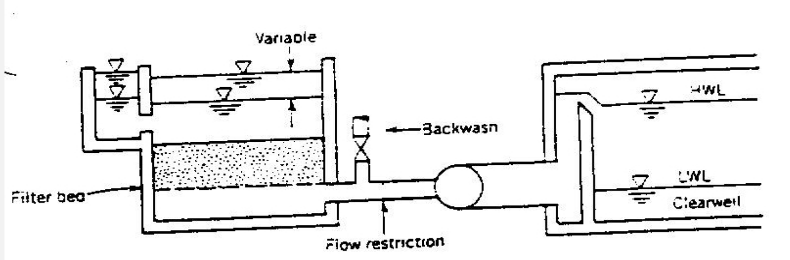


Figure 4-4 Gravity filter arranged for variable declining rate of filtration.



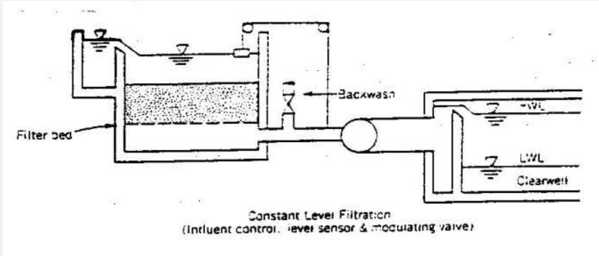
Declining Rate Filtration
(No influent control, no modulating valve, an orifice plate)

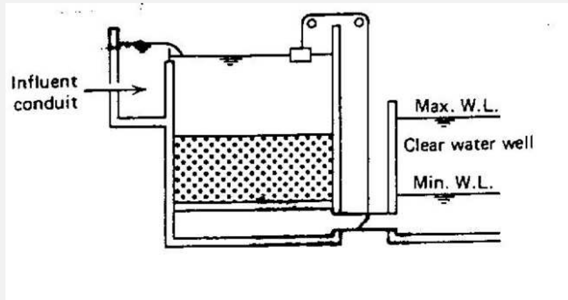
All filters are served by a common influent header or channel and flow enters the filter below the low water level in each filter → all filters operate at approximately the same water level and thus have the same available head

no rate of flow control system → a hydraulic restriction (usually orifice plate) may be used at the outlet side of the filterto restrict the initial filtration rate (which is about twice that of the average filtration rate)

B) DECLINING RATE FILTRATION

→ Water level in each filter is same





Rising steadily as the filters clog as a result of decreasing flow through the dirtier filters

cleaner filters pick up the capacity lost by the dirtier filters and their water level rises slightly to provide additional head needed.

Rising abruptly when a filter is taken out of service for backwashing

Dropping again after each backwashed filter is brought back into service

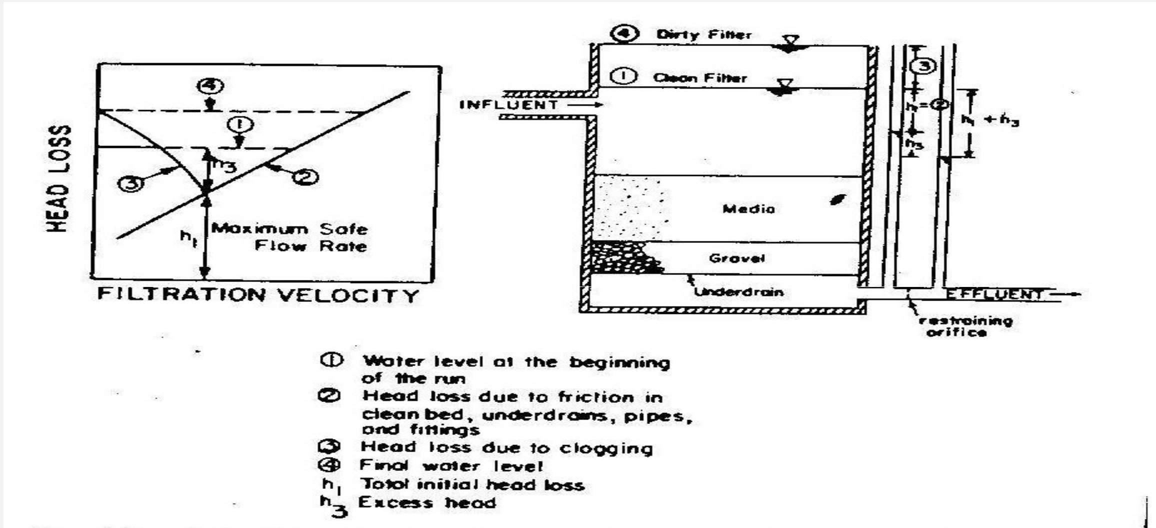


Figure 6.21. Heads and water levels in declining-rate filtration systems. Source: Adapted from Arboleda.

Cleaner filters operate at the high filtration rate

Dirtier filters operate at the lower filtration rates

B) DECLINING RATE FILTRATION

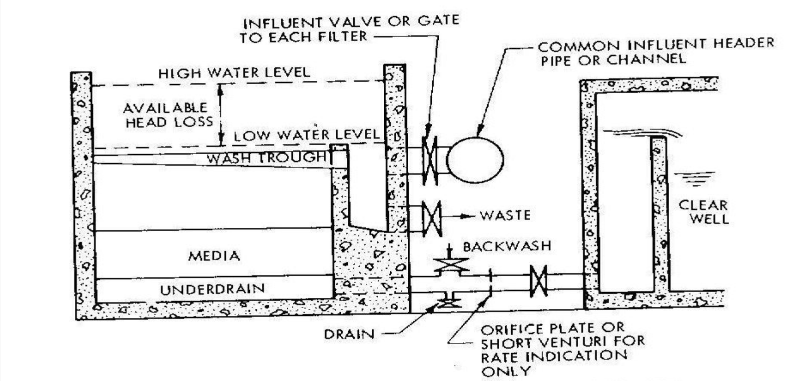
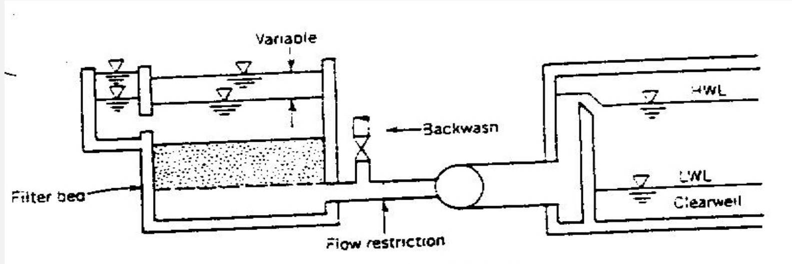


Figure 4–4 Gravity filter arranged for variable declining rate of filtration.



Declining Rate Filtration
(No influent control, no modulating valve, an orifice plate)

ADVANTAGES:

less total head is needed across the filter because the rate declines

better filter effluent quality

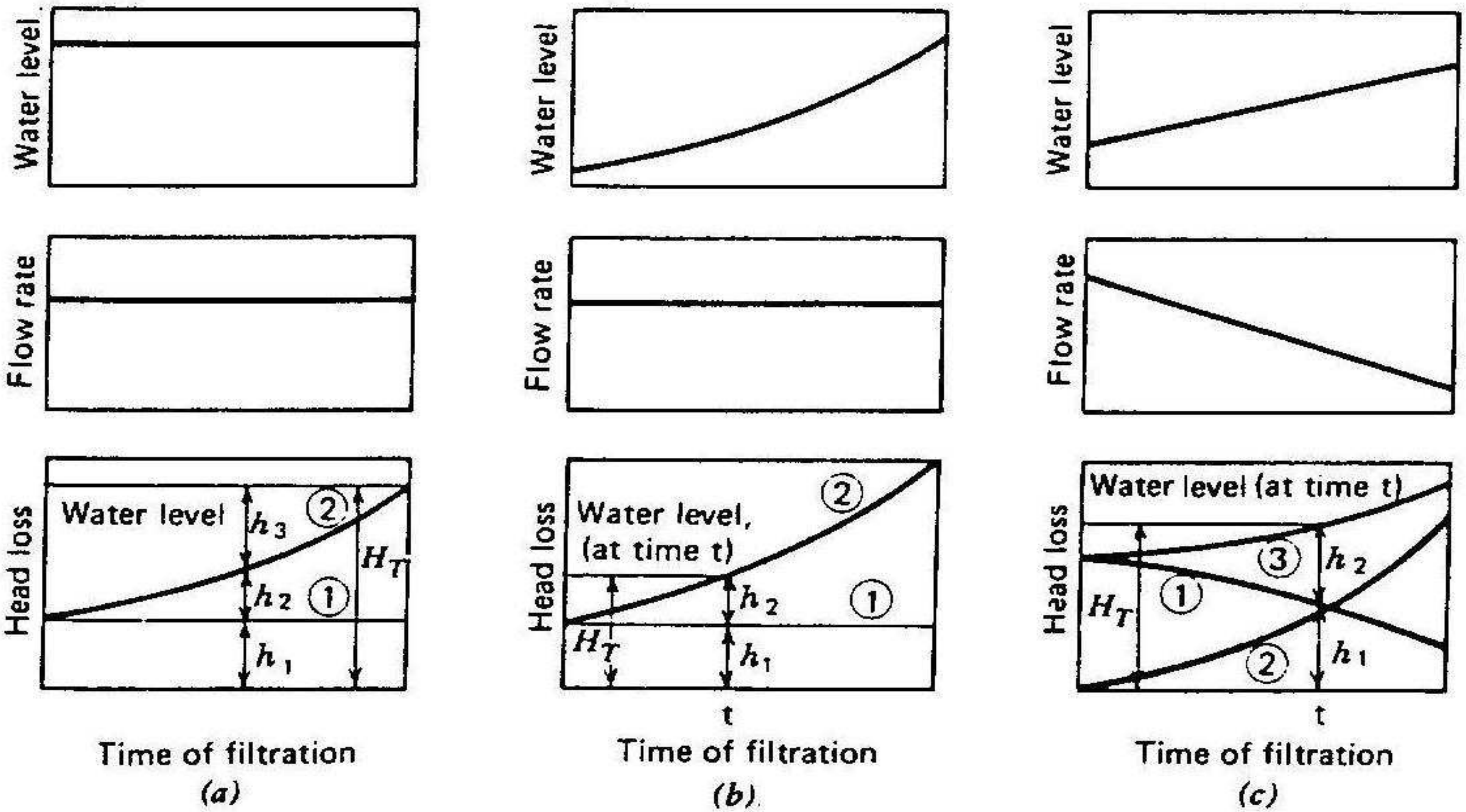


Figure 8.16. Head losses, flow rates, and water levels in filter control systems: (a) constant-rate filtration with rate controllers; (b) constant-rate filtration with increasing water level; (c) declining-rate filtration. One, h_1 = head loss due to clean bed, underdrains, valves, pipes and fittings; two, h_2 = head loss due to clogging of the filter bed; three, H_T = total head loss; h_3 = excess head (expended in rate controller or valve).

Filtration Hydraulics
Calculation of clean bed head loss

Type of flow

Laminar ($R_e < 6$)

Transitional or Turbulent

The flow through a clean filter of ordinary grain size (0.5-1mm) at ordinary filtration velocities (4.9-12m/h) would be in the <u>laminar range</u>.

Recent practice;

use of larger sized media

deeper filtration beds

higher filtration velocities

} flow regime TRANSITIONAL or TURBULENT

$$R_e = \frac{\psi . d . v}{\nu} = \frac{\psi . d . \rho . v}{\mu}$$

ϕ = *Shape factor* (ψ)

d = *Grain diameter*

v = *Filtration velocity*

μ = *Dynamic* viscosity

υ = Kinematic viscosity

Flow Regime

Laminar

→ Carman kozeny eqn.

→ Rose eqn.

Transitional or Turbulent

→ Ergun eqn.

→ Rose eqn.

Carman Kozeny Equation

$$h = \frac{F}{\psi} \cdot \frac{1-e}{e^3} \cdot \frac{L}{d} \cdot \frac{v^2}{g}$$

$$F = 150 \cdot \frac{1-e}{\mathrm{Re}} + 1.75$$

$$\mathrm{Re} = \frac{\psi d . v . g}{\mu}$$

$$h = \frac{150\mu}{\psi^2 d^2 g} \frac{(1-e)^2}{e^3} \frac{v}{g} L$$

$$h = \frac{150\mu}{\psi^2 d^2 g} \frac{(1-e)^2}{e^3} \frac{v}{g} L$$

First term of Ergun eqn.

Carman Kozeny Equation (for uniform media)

$$h = \frac{k\mu}{\rho g}\frac{(1-e)^2}{e^3}\left(\frac{a}{\forall}\right)^2 VL \; (k \approx 5)$$

Specific surface area $= \frac{6}{d}$ (for spherical)

$= \frac{6}{\psi d}$ (for irregular)

$$h = \frac{5\mu}{\rho g}\frac{(1-e)^2}{e^3}\left(\frac{6}{\psi d}\right)^2 \nu L$$

$$h = \frac{180\mu}{\rho g}\frac{(1-e)^2}{e^3}\frac{1}{\psi^2 d^2}\nu L$$

Carman Kozeny Eqn uniform media, laminar flow conditions

L =Depth of filter bed,m

d =Grain diameter,m

e =porosity

ψ =Shape factor

V=Filtration velocity, m/sec

Carman Kozeny Equation (for nonuniform media)

Each sieve fraction is considered as a distinct layer.

Assume → uniform porosity

$$h = \frac{1}{\psi}\frac{1-e}{e^3}\frac{L v^2}{g}\Sigma f_{ij}\frac{X_{ij}}{d_{ij}}$$

X_{ij} = % of particles (or fraction) remaining within adjacent sieves

d_{ij} = average particle size $\left(d_{eq}\right)_{ij} = \frac{d_1+d_2}{2}$ or $\sqrt{d_1 d_2}$

$$h = \frac{k\mu}{\rho g}\frac{(1-e)^2}{e^3} v \left[\frac{6}{\psi}\right]^2 \Sigma \frac{\chi_{ij}}{(d_{ij})^2} L$$

k= 5

Carman Kozeny Eqn
nonuniform media,
laminar flow
conditions

Ergun Equation

$$h = \frac{f}{\psi}\frac{1-e}{e^3}\frac{L}{d}\frac{v^2}{g}$$

$$f = 150\frac{1-e}{R_e} + 1.75$$

$$h = \left(150\frac{1-e}{R_e}+1.75\right)\left(\frac{1}{\psi}\frac{1-e}{e^3}\frac{L}{d}\frac{v^2}{g}\right)$$

$$h = \left(150\frac{(1-e)\mu}{\psi d\rho v}\frac{1}{\psi}\left(\frac{1-e}{e^3}\right)\frac{L}{d}\frac{v^2}{g}\right) + \left[1.75\frac{1}{\psi}\frac{(1-e)}{e^3}\frac{L}{d}\frac{v^2}{g}\right]$$

$$h = \frac{150\,\mu\,(1-e)^2\,L\nu}{\psi^2 d^2 \rho e^3 g} + 1.75\,\frac{1}{\psi}\,\frac{(1-e)}{e^3}\,\frac{L}{d}\,\frac{\nu^2}{g}$$

$$\frac{h}{L} = \frac{4.17\mu}{\rho g}\,\frac{(1-e)^2}{e^3}\left(\frac{a}{v}\right)^2 v + k_2\,\frac{(1-e)}{e^3}\left(\frac{a}{v}\right)\frac{v^2}{g}$$

$$\frac{a}{v} = \frac{6}{\psi d}$$

For laminar flow

For transitional or turbulent flow

$k_2 = 0.29$

later reported as

$k_2 = 0.48$ for crushed porous solids

For non-uniform media:

$$\frac{a}{\forall} = \Sigma \chi_i \left(\frac{a}{\forall}\right)_i = \Sigma \chi_i \frac{6}{\psi . d_i}$$

EXAMPLES ABOUT CLEAN BEDHEADLOSS CALCULATIONS IN FILTERS

A) SINGLE MEDIUM FILTERS

Example #1 : Headloss across a bed of uniform size particles

Water at 20^0C is passed through a bed of uniform sand at a filtering velocity of 5 m/hr. The sand grains are 0.4 mm in diameter with a shape factor of 0.85 and a specific gravity of 2.65. The depth of bed is 0.67 m and the porosity 0.4. Determine the headloss through the bed.

at 20^0C; $\mu = 1.002 \times 10^{-3}$ kg/m.sec, $\rho = 998.2$ kg/m^3

Example #2 : Determination of headloss across a bed of nonuniform particles

Water at 20^{0}C is passed through a filter bed at 4.32 m/hr. The bed is 0.75 m deep and is composed of nonuniform sand (sp. gravity= 2.65) stratified so that the smallest particles are on top, the largest on bottom. The porosity and shape factors are 0.4 and 0.85 throughout the depth of bed. The size distribution of the granules given in the table below. Determine the headloss for clean water flow through bed.

at 20^{0}C; μ = 1.002x 10^{-3} kg/m.sec, ρ= 998.2 kg/m^3

Sieve Analysis Results:

U.S Sieve No.		Particle Size range, mm		Weight fraction retained, x_{ij}
Passing	Retained	Passing	Retained	
	14		1.41	0.01
14	20	1.41	0.84	0.11
20	25	0.84	0.71	0.20
25	30	0.71	0.60	0.32
30	35	0.60	0.50	0.21
35	40	0.50	0.42	0.13
40		0.42		0.02

B) DUAL MEDIUM FILTERS

Example #3 : Determination of headloss across a dual media (each layer is uniform)

Determine the clear water headloss in a filter bed composed of 0.3 m of uniform anthracite (with an average size of 1.6 mm) placed over 0.3 m layer of uniform sand (with an average size of 0.5 mm) for a filtration rate of 160 L/m^2.min.

Porosity for both anthracite and sand layer = 0.4

Shape factor for both anthracite and sand layer = 1 (spherical)

at 20^{0}C; μ = 1.002x 10^{-3} kg/m.sec, ρ= 998.2 kg/m^3

Example #4 : Determination of headloss across a dual media (each layer is nonuniform)

Calculate the initial headloss in a dual media filter containing anthracite and sand with depth of 0.45 m and 0.30 m respectively. The sphericities of the sand and anthracite are 0.95 and 0.72, respectively. The porosities of anthracite and sand are 0.55 and 0.40, respectively. Filtration velocity is 175 m^3/m^2.d.

at 10^0C; μ = 1.307x 10^{-3} kg/m.sec, ρ= 999 kg/m^3

Sieve Analysis Results:

for anthracite layer		
d_1, mm	**d_2, mm**	**Mass fraction retained**
0.72	1	0.2
1	1.18	0.2
1.18	1.27	0.2
1.27	1.53	0.2
1.53	1.81	0.2

for sand layer		
d_1, mm	**d_2, mm**	**Mass fraction retained**
0.51	0.61	0.2
0.61	0.68	0.2
0.68	0.74	0.2
0.74	0.82	0.2
0.82	0.93	0.2

-BACKWASH HYDRAULICS-

When water flows through the bed from the bottom towards top → Filter grains are lifted . Expansion of sand bed takes place

To hydraulically expand the bed:

Headloss must at least equal to the buoyant weight of the particles in the fluid

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

h_{fb} = Head loss required to initiate expansion, m

L= Bed depth, m

e= Porosity of fixed bed

ρ_m = Media density, kg/ m^3

ρ_w = Water density, kg/ m^3

The headloss through an expanded bed is essentially unchanged because the buoyant weight of the bed is constant.

Weight of packed bed=weight of fluidized bed.

$$h = L(1-e)\frac{\rho_m - \rho_w}{\rho_w} = L_{fb}(1-e_{fb})\frac{\rho_m - \rho_w}{\rho_w}$$

$L_{fb} =$ Depth of fluidized bed, m

$e_{fb} =$ The porosity of fluidized bed

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

$$e_{fb} = \left(\frac{v_b}{v_t}\right)^{0.22}$$

Richardson Zaki eqn.

v_b =Backwash velocity $\left(\frac{Q_{backwash}}{A}\right)$

v_t =Settling velocity of particles

$$L_{fb} = L \frac{(1-e)}{1-\left(\frac{v_b}{v_t}\right)^{0.22}} \quad \text{for UNIFOR M MEDIA}$$

$$L_{fb} = L(1-e)\sum \frac{\chi_{ij}}{1-\left(\frac{v_b}{v_{t,ij}}\right)^{0.22}} \quad \text{for NON UNIFORM MEDIA}$$

For stratified bed $\longrightarrow$ total expansion= $\sum$ expansion of individual layers

Example: Finding the expanded depth of uniform medium

Filter medium → sand grains (0.4mm in diameter)

ψ = 0.85

specific gravity= 2.65

depth of the bed=0.67m

porosity=0.4

T=20 C → $\mu = 1.002 . 10^{-3} N.s / m^2$

$\rho_w = 998.2 \ kg / m^3$

Determine the required backwash velocity to expand the bed to a porosity of 0.7.

Example: Determine the headloss during backwash for a filter bed consisting of 0.6 m sand with a porosity of 0.45.

$$\rho_{bed} = 2650\, kg / m^3 \quad , \quad \rho_{water} = 1000\, kg / m^3$$

Example (Finding the expanded depth of a non-uniform bed):

Filter bed → 0.75m deep, composed of non-uniform sand (sp. gravity 2,65)

porosity:0.4 shape factor: 0.85

at $20^{o}C$ → $\mu = 1.002 . 10^{-3} kg/m.sec$

$\rho_w = 998.2 \ kg/m^3$

This bed is to be backwashed at a velocity of 1.5 10^{-2} m/sec. Determine the depth of expanded bed

Sieve Analysis Results:

US Sieve No		Particle size/mm		Mass fraction retained, X_{ij}
	14		1.41	0.01
14	20	1.41	0.84	0.11
20	25	0.84	0.71	0.20
25	30	0.71	0.60	0.32
30	35	0.60	0.50	0.21
35	40	0.50	0.42	0.13
40		0.42		0.02

MINIMUM FLUDIZATION VELOCITY (Vmf)

Velocity required to initiate fluidization ⟶ V_{mf}

At the point of beginning of fluidization:

Fixed bed headloss = Fluidized bed headloss

$$h = \frac{150\,\mu(1-e)^2 L V_{mf}}{\psi^2 . d^2 . \rho . e^3 . g} + 1.75\,\frac{1}{\psi}.\frac{(1-e)}{e^3}.\frac{L}{d}.\frac{V_{mf}^{\;2}}{g} = L(1-e)\frac{\rho_m - \rho_w}{\rho_w}$$

Wen & Yu (1996) → eliminated both ψ and e

$$V_{mf} = \frac{\mu}{\rho . d_{eq}} \left(33.7^2 + 0{,}0408\,Ga \right)^{0{,}5} - \frac{33{,}7\mu}{\rho . d_{eq}}$$

$$G_a = galileo \ number = d_{eq}{}^3 . \frac{\rho_w (\rho_m - \rho_w) g}{\mu^2}$$

For a sand bed containing gradation in particle size, the fluidization velocity is not same for all particle

smaller grains became fluidized at a lower velocity then larger grains do

Calculation of Vmf for the coarser grains → to ensure that the entire bed is fluidized

d_{90} sieve size → would be a practical

Suggestion for backwash rate=1.3 Vmf

Example: Calculate the minimum fluidization velocity for an anthracite bed having following characteristics

$$d_{90} = 2{,}9 \text{ mm} \qquad \rho_{anthracite} = 1600 \text{ kg/m}^3$$

$$T = 20\,^{o}C \rightarrow \mu = 1.002 \,.10^{-3} \text{ kg/m sec}$$

$$\rho_w = 998 \text{ kg/m}^3$$

Example: Calculate the minimum fluidization velocity for a non-uniform sand media having following characteristics

$d_{90} = 0.93\,mm$

$T = 10^{o}C$

$\mu = 1.306.10^{-3}$

$\rho = 999.7\,kg/m^{3}$

$\psi = 0,75$

porosity of unstratifi ed bed = 0.39

porosity of stratified bed = 0.42

$V_{mf} = ?$

Slow Sand Filtration

very low filtration rate (0.1 – 0.4 m/hr)

Effective size of sand used = 0.1 – 0.3 mm

Uniformity coeff. = 2-3

Thickness of the bed = 1 – 1.5 m

Supporting gravel layer = 0.3 –0.5 m (prevents the penetration of fine sand particles into lower layers)

large space requirement

underdrain → normally perforated pipes placed within the lower portion of the supporting gravel layer

conventionaly operated at a constant rate

Slow Sand Filtration

Removal Mechanism:

SAND particle size → smaller than that for rapid sand filters
all of the suspended materials being removed at the filter surface

a mat of biological organisms is allowed to develop at the water –sand interface which aided in the filtration process (**Schmutzdecke Layer**)

Accumulation of Schmutzdecke layer → ranges between 6 hr to 30 days

optimum operation is not obtained till Schmutzdecke layer is formed

Slow Sand Filtration

Principal Uses:

removal of organic matter and pathogenic organisms from raw waters of relatively low turbidity (< 50 NTU)

In Schmutzdecke layer → biological treatment
reduction of total bacteria count by a factor of 10^3 to 10^4
good for complete removal of Giardia Cysts.

for low turbidity surface waters →cheapest, simplest and the most effiicient method

Operation:

During operation, the level of water above the filter surface will gradually increase as the upper layers of the sand become plugged.

When the water level above the filter medium has increased to 1.25 to 2 m , the filters are cleaned

Slow Sand Filtration

Cleaning of bed:

sand bed is cleaned by removing schmutzdecke along with a small amount of sand depth, an operation known as scraping (either by hand or mechanically)

Scraping of the small amount of media → decrease of sand bed height

When the bed reaches a minimum thickness of 0.5 – 0.8 m
→ resanding of filters (usually not frequently than once a month)

Pressure Filters

The filter medium is contained in a steel pressure vessel

may be a cylindrical tank with vertical axis
may be a horizontal axis cylindrical tank

tend to be used in small water systems (e.g industrial applications)

operating principals are identical with those of gravity filters

water to be filtered enters the filter under pressure and leaves at slightly reduced

pressure becuse of the headloss encountered in the filter medium, underdrain and piping

Pressure Filters

Advantages & Disadvantages

influent is under pressure → higher filtration rate
high terminal head loss

water enters and leaves
the filter under pressure → no negative pressure can ever exist in filter medium

filter medium is in a
closed vessel (i.e, it is not conveniently visible) → proper backwashing is difficult