The University of Zambia
School of Engineering
Dept. of Civil & Environmental Engineering

CEE 4412: Environmental Engineering I

Water Supply – Sedimentation and Filtration

JMT
August 2021

SEDIMENTATION

Unit operation for the removal, by settling of **settleable suspended solids**.

Significance of Suspended Solids

- ❖ They make water aesthetically unpleasant
- ❖ They are associated with micro-organisms
- ❖ They shorten filter runs (rapid clogging of filters)
- ❖ May settle in the distribution system

SEDIMENTATION

Applications

- ❖ In the removal of readily settleable particles (plain sedimentation)
- ❖ In the removal of flocculated colloids
- ❖ Removal of precipitated hardness & iron/Manganese

High removal efficiencies in sedimentation tanks:

- ❖ Determines subsequent loading on filter
- ❖ Has marked influence on capacity of filters
- ❖ Affects filter run
- ❖ Has influence on quality of filtered water

SEDIMENTATION

Sedimentation takes advantage of the gravitational forces, density and size of the particles. Therefore, suspended particles will only settle if:

- The particle size is greater than the colloidal range as in the colloidal range, laws of diffusion are predominant
- The density is greater than that of water (the liquid)

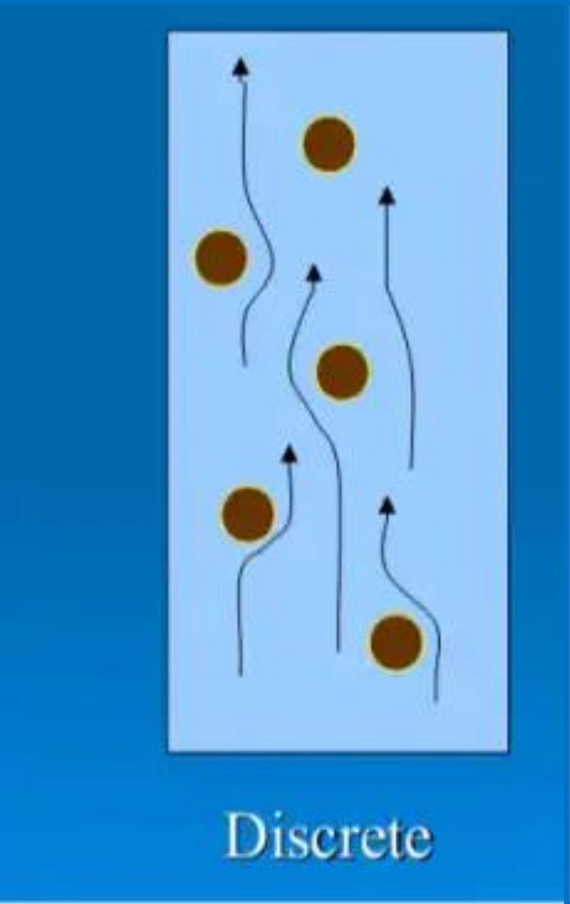
SETTLING CHARACTERISTICS

DISCRETE

- Particle does not change shape or size during settling with adequate distance between them to avoid disturbances (drag)

SETTLING CHARACTERISTICS

DISCRETE



SETTLING CHARACTERISTICS

- Stokes law as follows:-

$$V_s = \frac{g(S-1)d^2}{18\mu}$$

Where

- Vs = terminal velocity
- d = diameter of particle
- S = specific gravity of particle
- g = gravitational constant
- μ = Kinematic viscosity

Kinematic Viscosity*Density=Dynamic viscosity

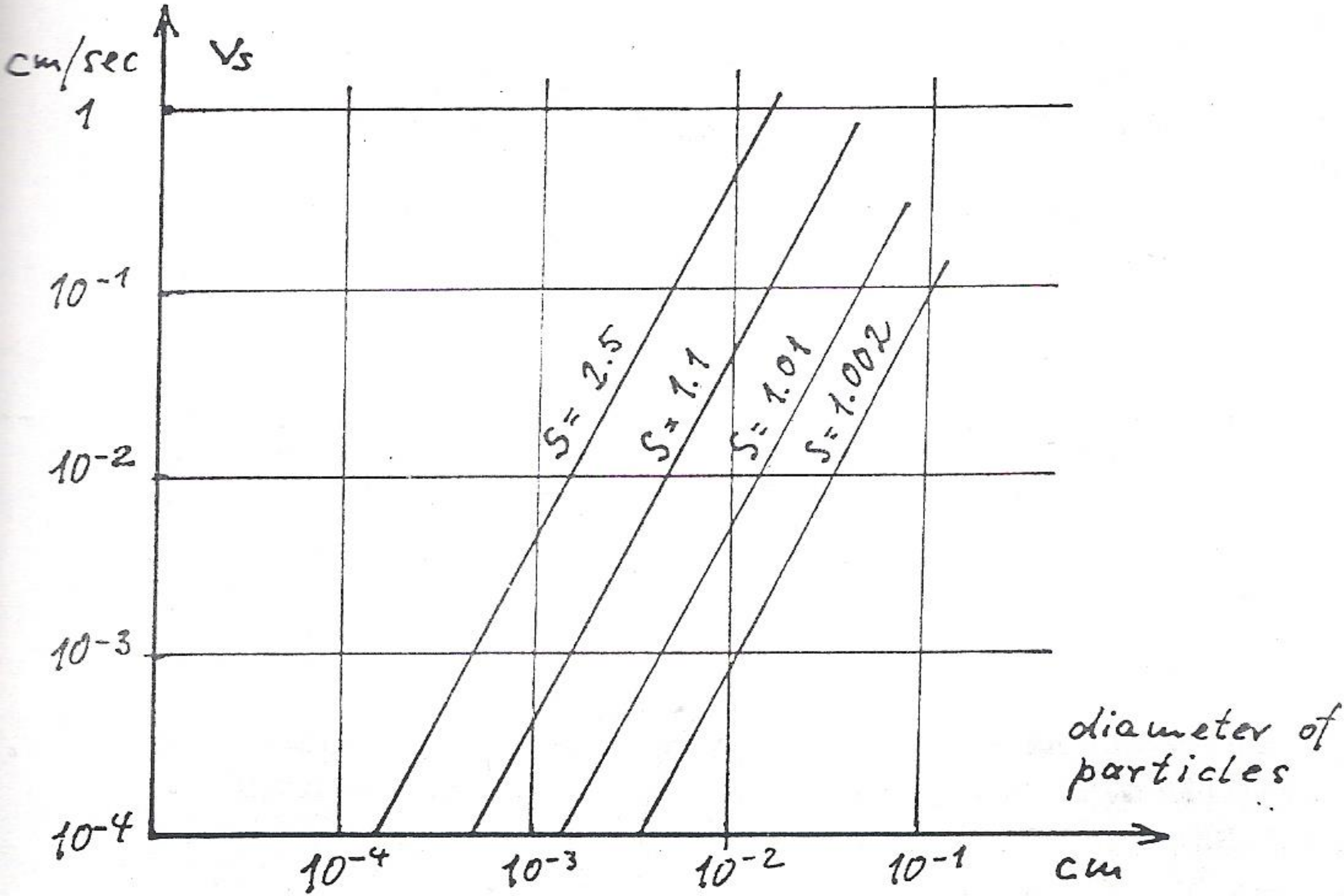


Figure 18. Terminal Settling velocities for spherical particles at 10°C

Effect of decreasing sizes of particles on settling rate

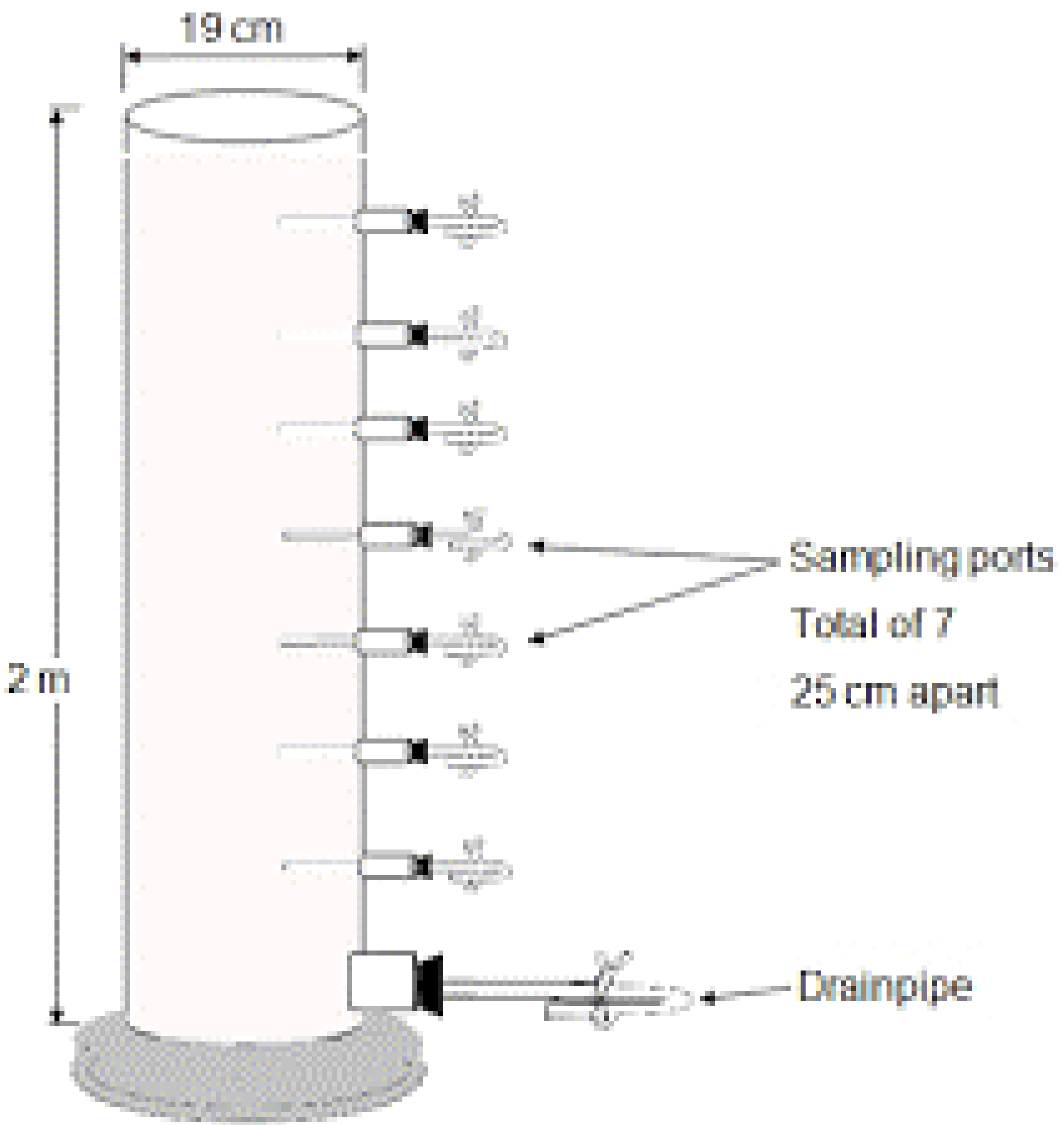
Diameter of particle (mm)	**Order of Size**	**Time required to settle***
10	Gravel	0.3 seconds
1	Coarse Sand	3 seconds
0.1	Fine Sand	38 seconds
0.01	Silt	33 minutes
0.001	Bacterial	55 hours
0.0001	Colloidal Particles	230 days
0.00001	Colloidal Particles	6.3 years
0.000001	Colloidal Particles	63.3 years minimum

Calculations based on spheres with a specific gravity of 2.65 to settle through 30cm

Significance of above calculations and graphs

- To get Vs which is important in design of sedimentation tanks
- In practice, it is usually not possible to estimate the sizes and densities of particles that need to be removed.
- Hence, experiments need to be conducted on the raw water (i.e. sedimentation tests)

Significance of above calculations and graphs



Other Types of Settling

HINDERED SETTLING

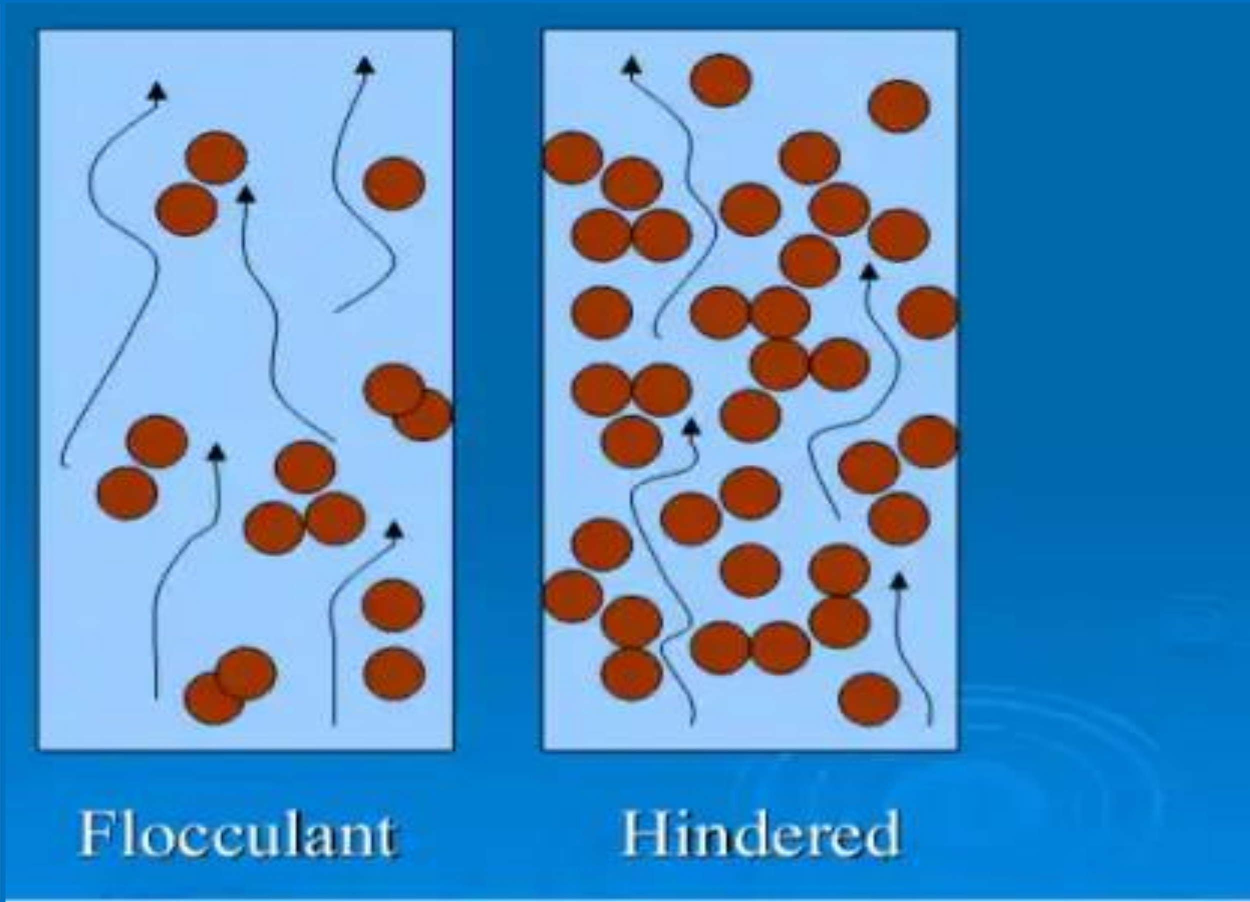
- Where particles are densely dispersed within the fluid, resulting in drag thus reducing the Vs.

FLOCCULENT SETTLING

- Particles keep on growing. Hence initially, the settling velocity increases. But as the particles go towards the bottom, the effects of hindered settling come into play.

SETTLING CHARACTERISTICS

Hindered and Flocculent Settling



Hindered Settling

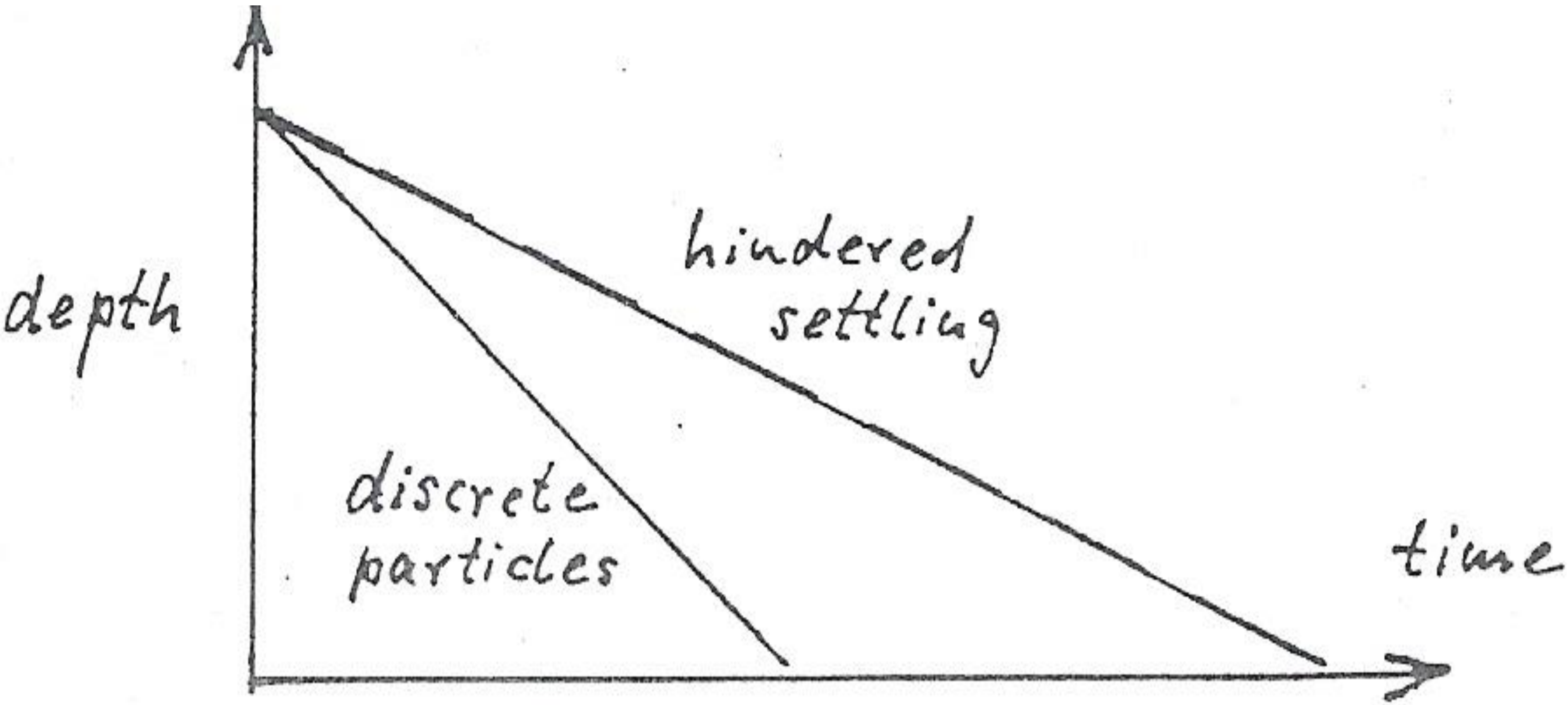


Figure 19. Hindered settling

Flocculent Settling

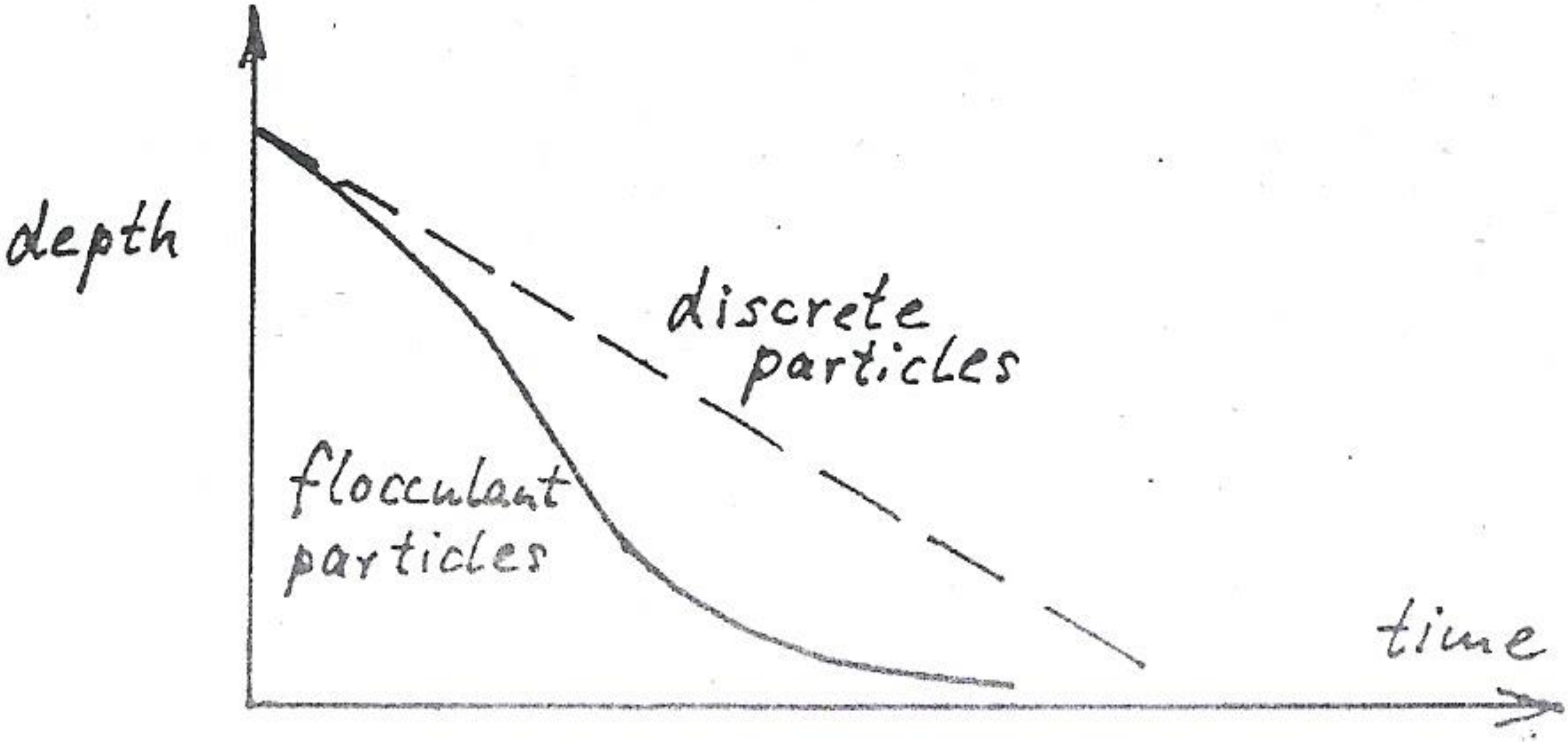


Figure 20. Settling of flocculant suspensions

Sedimentation in Practice

- Continuous and not batch
- Sedimentation tanks are "continuous flow basins".
- Particle move both vertically (downwards) and horizontally.

Ideal Sedimentation

Under ideal conditions, the following assumptions are made:-

- There are quiescent conditions in the settling zone (no currents no turbulences)
- The flow is uniform and steady across the settling zone
- The concentration of the suspended solids is uniform when the water enters the settling zone
- Once particles have reached the bottom, they stay there.

Ideal Settling Basin

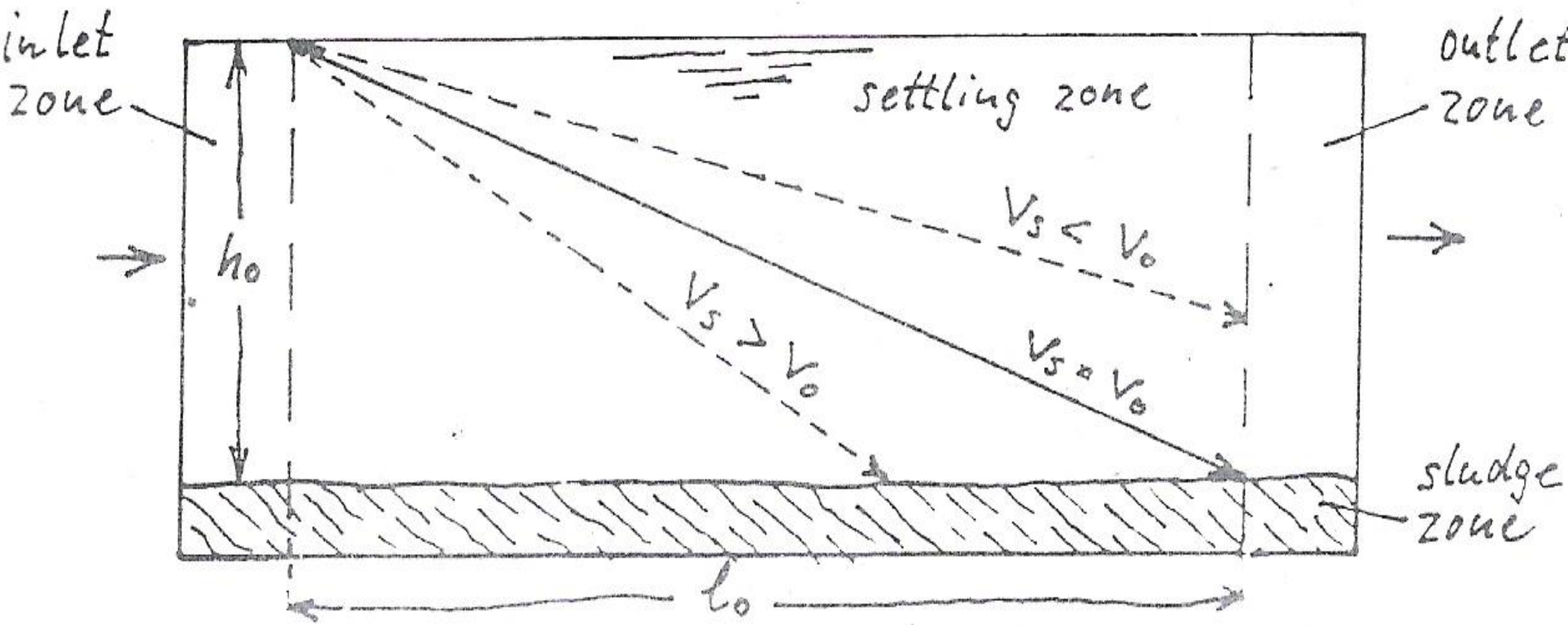


Figure 21. Ideal settling basin

Ideal Settling Cont'

- In above case, all particles with Terminal Velocity V_o greater than the horizontal velocity will settle out and will be deposited at the bottom.
- Otherwise, they will float away

Designing Sedimentation Tanks

- First determine settling velocity of smallest particle to be removed
- This can be through calculations or experiments
- Let us assume that the tank of Volume V will treat a quantity of water =Q, then

Designing Sedimentation Tanks Cont'

- Retention time $t_o = V/Q$ -------------------- (1)
- Also $v_o = h_o/t_o$ ---------------------------------- (2)
- From (2) $t_o = h_o/v_o$ ---------------------------- (3)

Equating (1) and (3) we get

- $V_o = h_o/V/Q = Qh_o/V$

Designing Sedimentation Tanks Cont'

- But Volume $V = h_o * A$

- Therefore $V_o = Q/A \; ((m^3/s)/m^2)$ or m/s

The above is the most important parameter in the design of sedimentation tanks and is called the Overflow Rate or the Surface Loading Rate or the Flow Through Velocity

Designing Sedimentation Tanks Cont’

- Remember that in the design work, you will get the V_o through experiments
- Q will be determined from water demand computations
- Then you get the Area and design is done (Other details like depth you get from standards)

Settling Basins in Practice

Conditions are non ideal and settling efficiency is reduced by factors like:-

❖ CURRENTS

- Eddy currents (set up by incoming water - whirlpools) due to non existence of ideal inlet
- Surface currents - induced by wind
- Vertical convection currents (when surface gets cooler than bottom)
- Density currents (when incoming water is cooler than water in the basin)

Settling Basins in Practice

- Short circuiting (retardation)
  - Where water is not uniformly distributed at the inlet and/or at the outlet

- Scouring (of bottom deposits)
  - This occurs when the tank length is very long compared to its depth (or width). When designing, make sure the length to depth ration is less than 10 (i.e. $l/d < 10$)

Significance of Non -Ideal Conditions

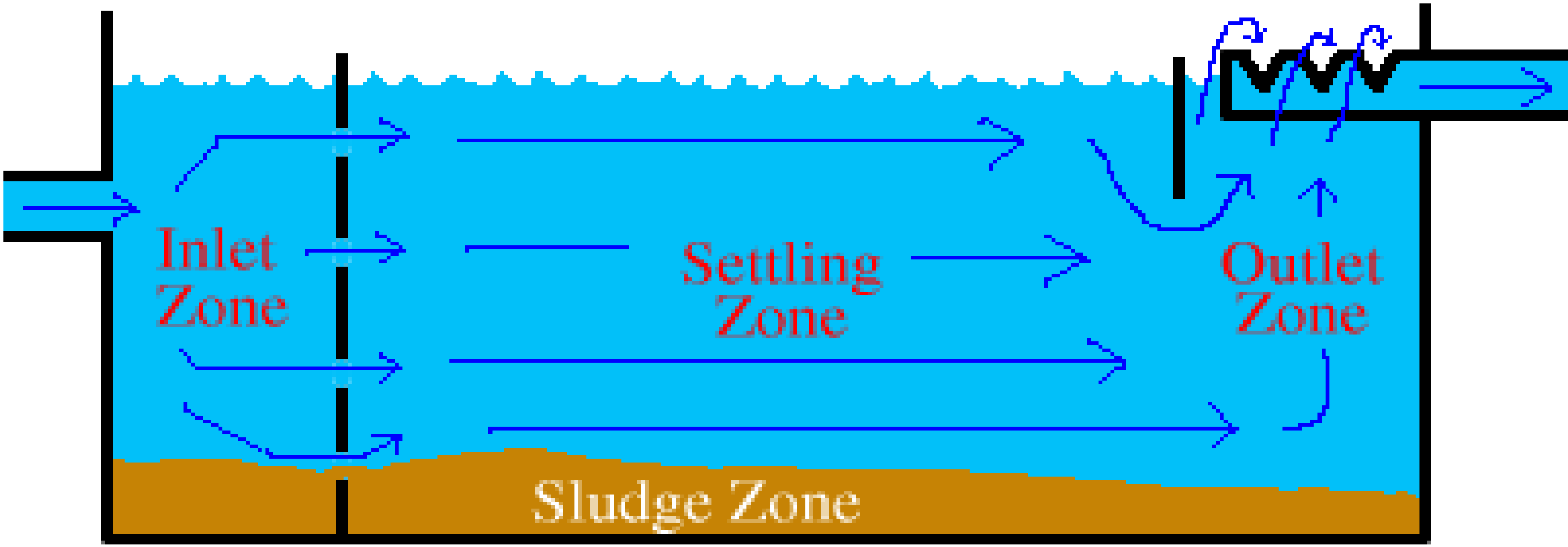
- ❖ Surface area to be increased
- ❖ Or flow rate to be reduced

Other aspects of Significance

- Sedimentation efficiency can also be improved by using tube settlers

Types of Sedimentation Tanks

- Rectangular manually, hydraulically or mechanically cleaned



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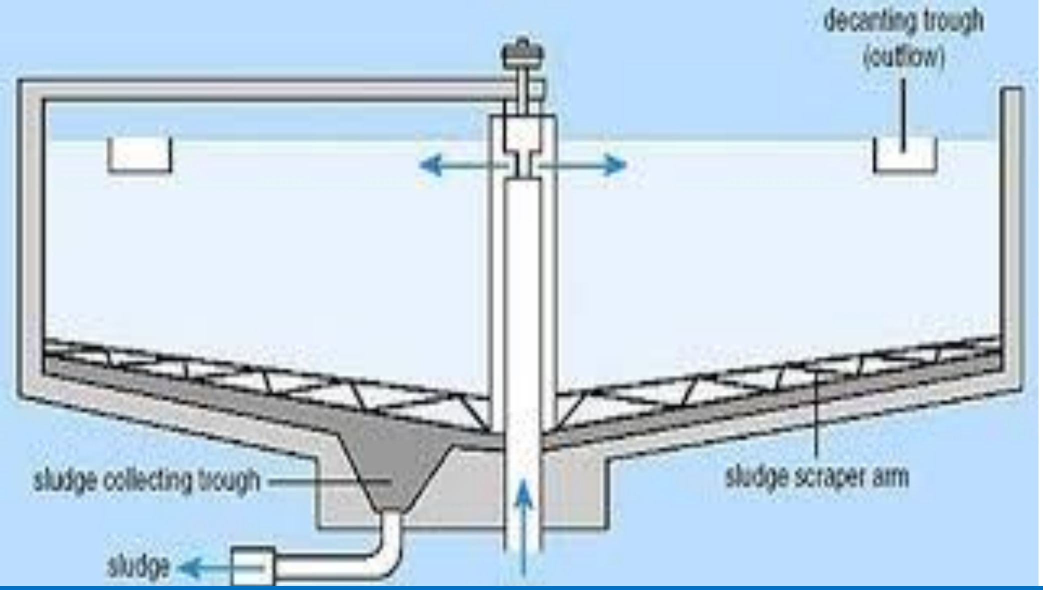
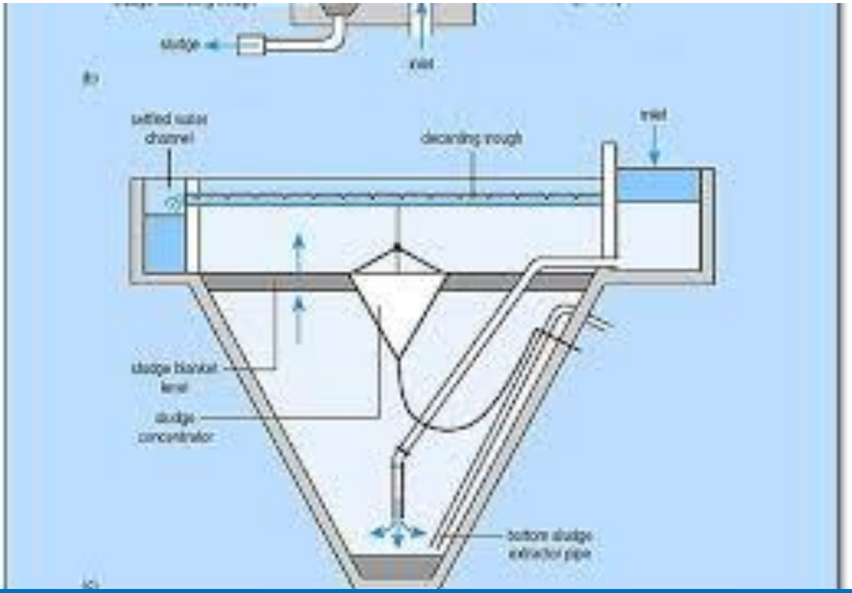
Types of Sedimentation Tanks

- Circular and conical usually mechanically or hydraulically cleaned





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Other Design Aspects of Sedimentation Tanks

i. Depth: Ranges between 2.5 to 5m but generally 3.0–3.5m

ii. Diameter: Can go up to 70m but generally only up to 35m (Currents)

iii. Length: Can go up to 100m but generally 35m is taken as limit (Currents)

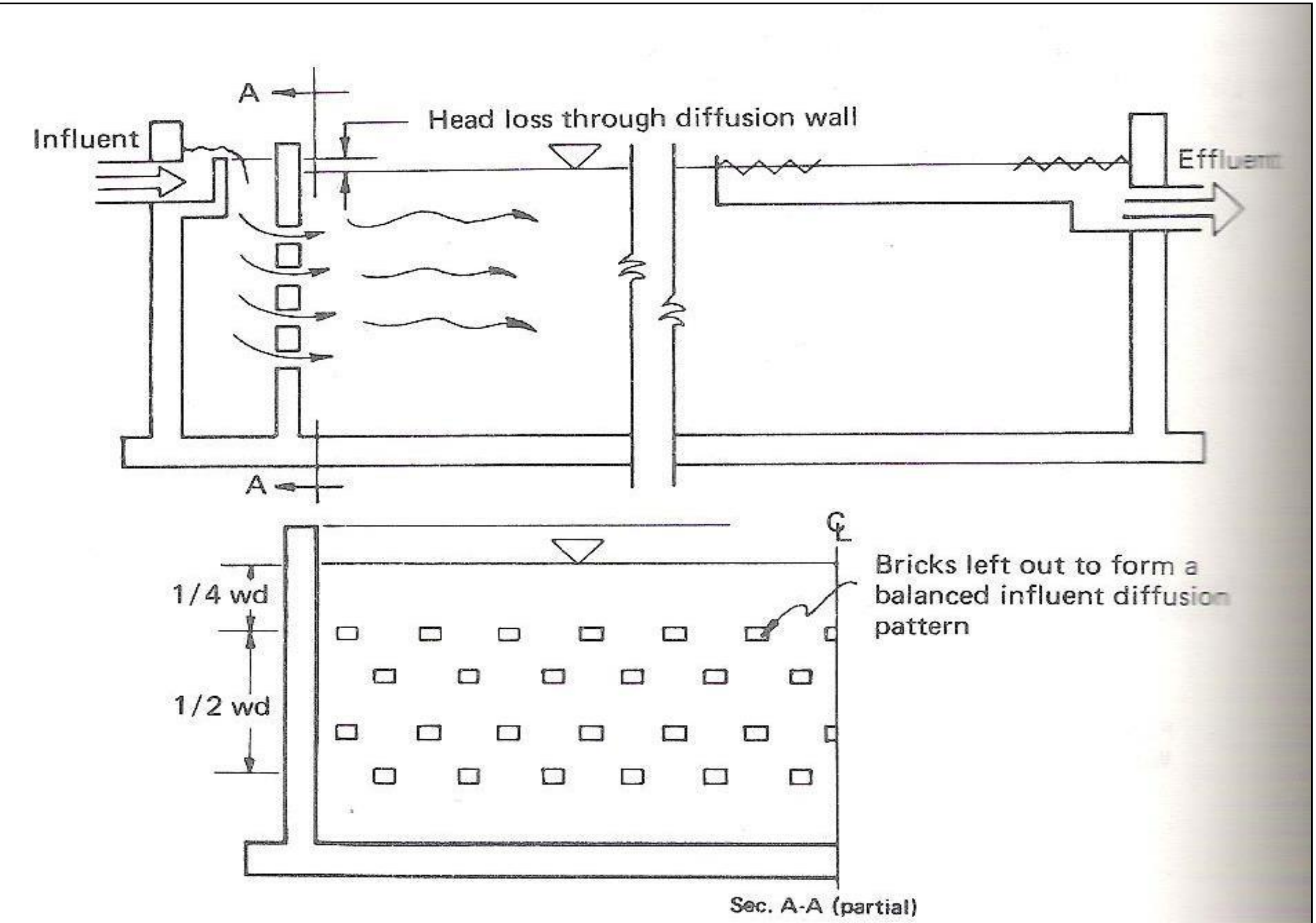
iv. Width: 5 to 10m

v. Length to depth ratio: <10

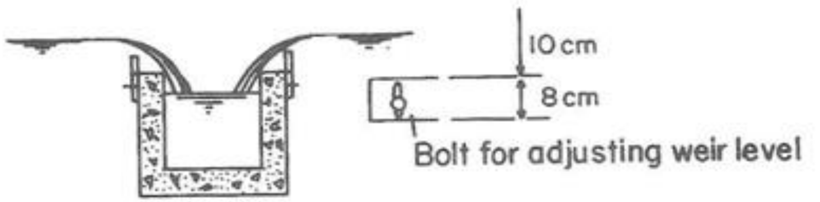
vi. Bottom Slopes: 8% and 1% for Circular and rectangular tanks respectively

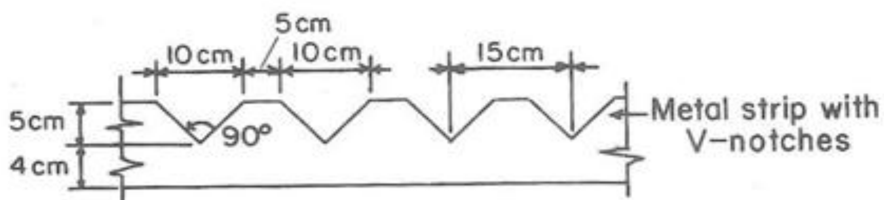
Inlet and Outlet Hydraulics

- Aim at uniform distribution and collection



Sedimentation – Outlet arrangements





Example

- Design a rectangular sedimentation tank given the following information
  - Smallest particle to be removed $=10^{-3}$cm
  - Specific gravity = 2.5
  - Flow rate= $100m^3/h$

Solution

- In this case, get V_o from Graphs = $8*10^{-3}$cm/s = 0.29m/h
- Get Area from V_o = Q/A

$$A = 100m^3/h/0.23m/h$$

$$A = 345m^2$$

Select h = 3.5

Example Cont’

Calculate Length

Condition: l/d >10

l/3.5 >10

Therefore l = 35m

Width: A=l*w = w = A/l = 345/35 = 9.85m OK

Retention time = V/Q or h_o/vo = (345*3.5)/100 or

3.5/0.29 = 12hours.

What to Remember

- Calculations are based on ideal conditions

- Therefore dimension would have to be adjusted to meet real situation conditions

FILTRATION

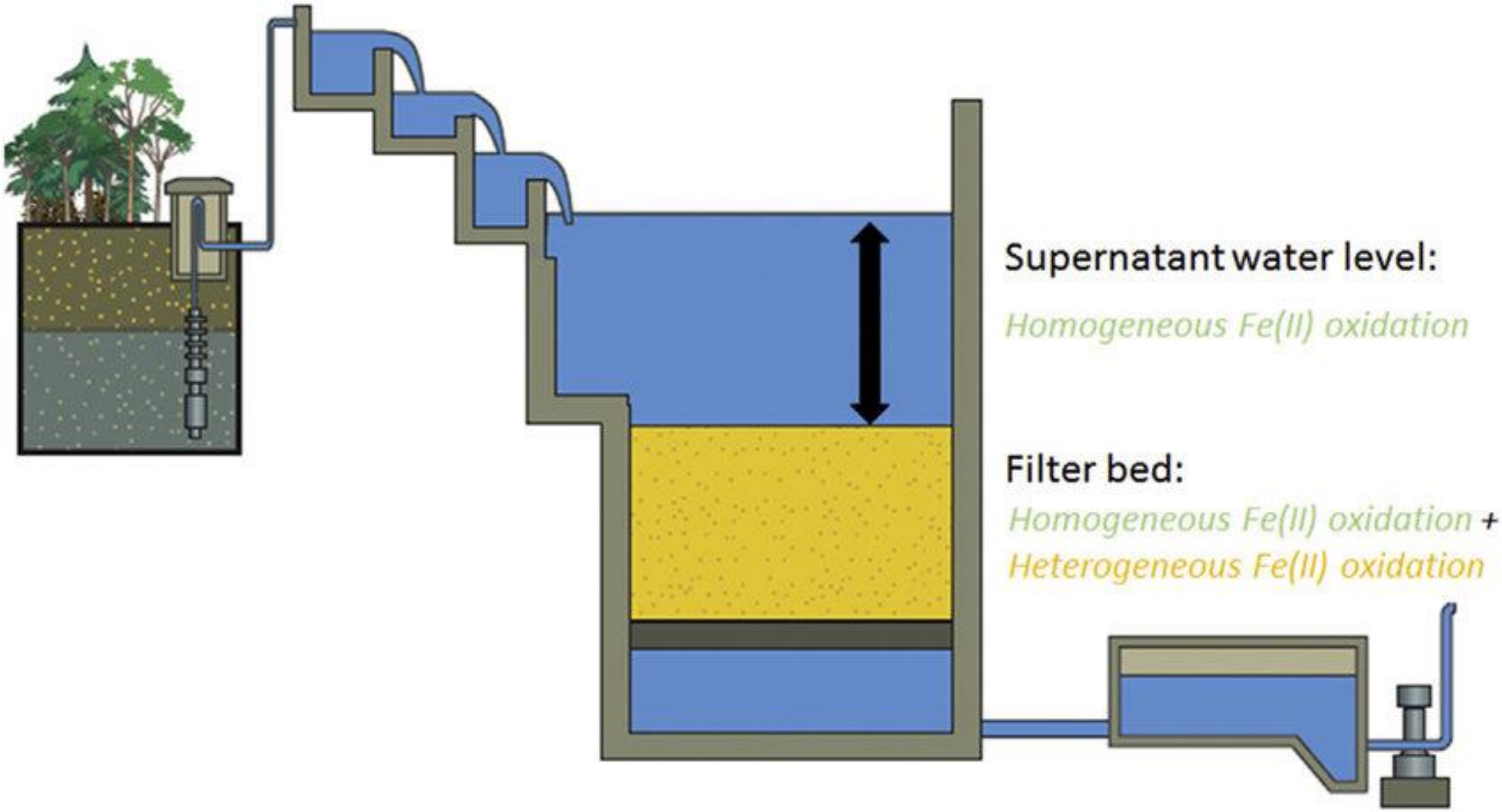
Unit operation for the removal of suspended solids and micro-organisms (SSF)

Applied :-

- As only unit operation for surface water (Direct Filtration)
- After plain sedimentation
- After coagulation/flocculation and Sedimentation
- After precipitation of hardness

FILTRATION

❖ After aeration in removal of Fe an Mn



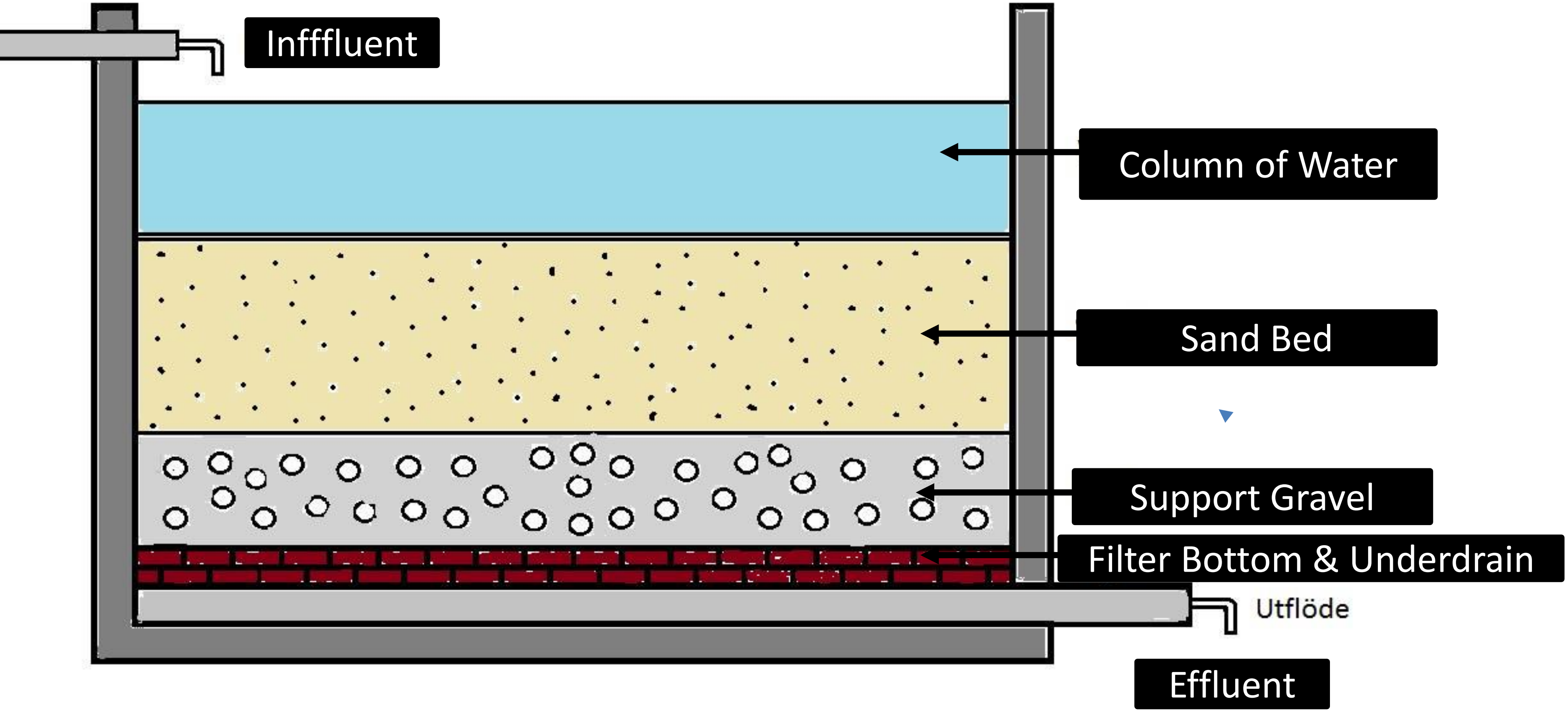
What is a Filter?

- A basin or tank filled with sand and gravel (Filter and support media)
- Several types exist among which are:
  - slow sand filters
  - Gravity Rapid Sand Filters (RSF)
  - Pressure Filters

What are the Main Features

- Column of water
- Sand bed (Filter media –artificial)
- Support gravel (Support media)
- Filter bottom and under drains
- Inlet and outlet control systems

What are the Main Features



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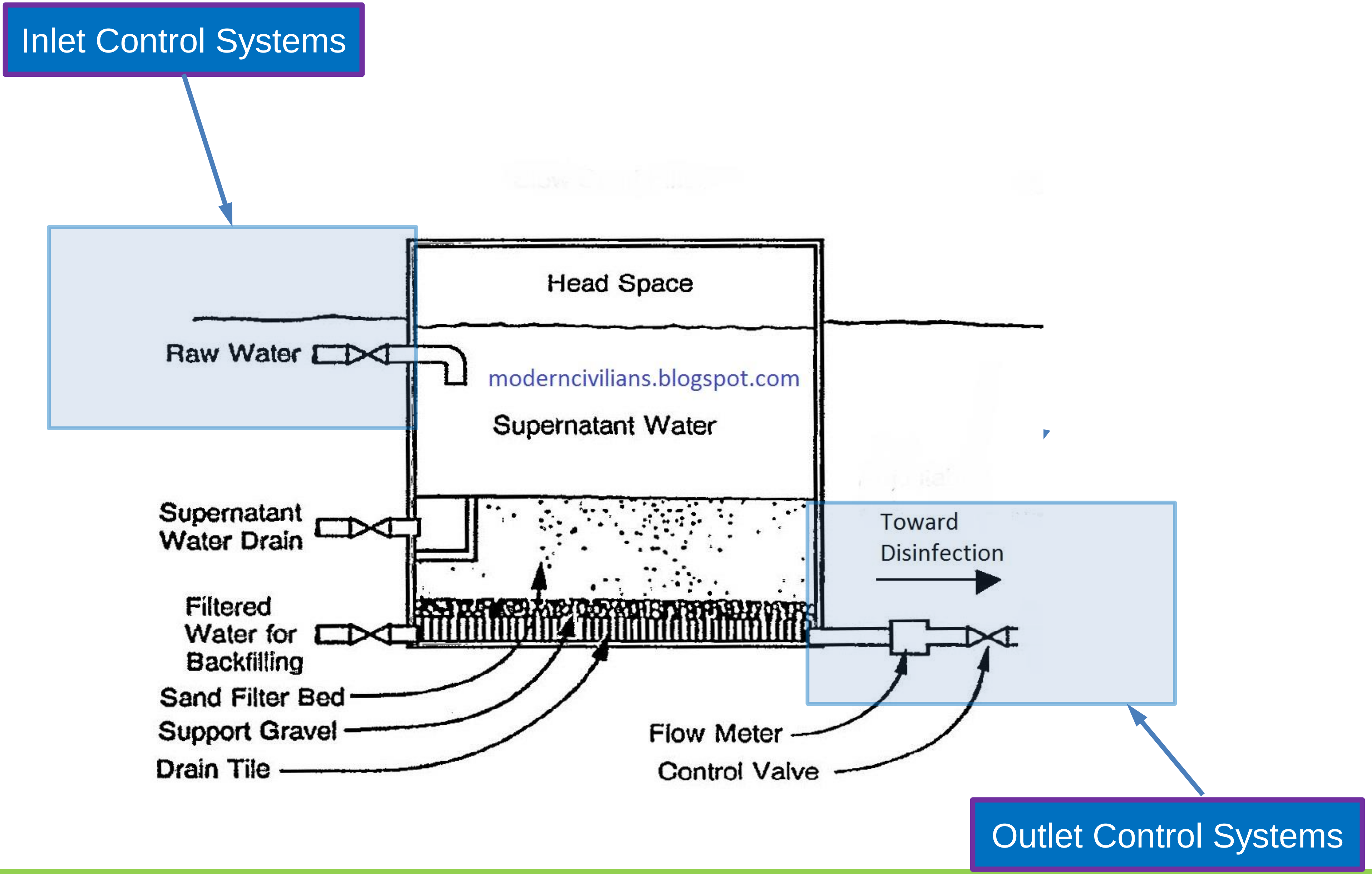
What are the Main Features



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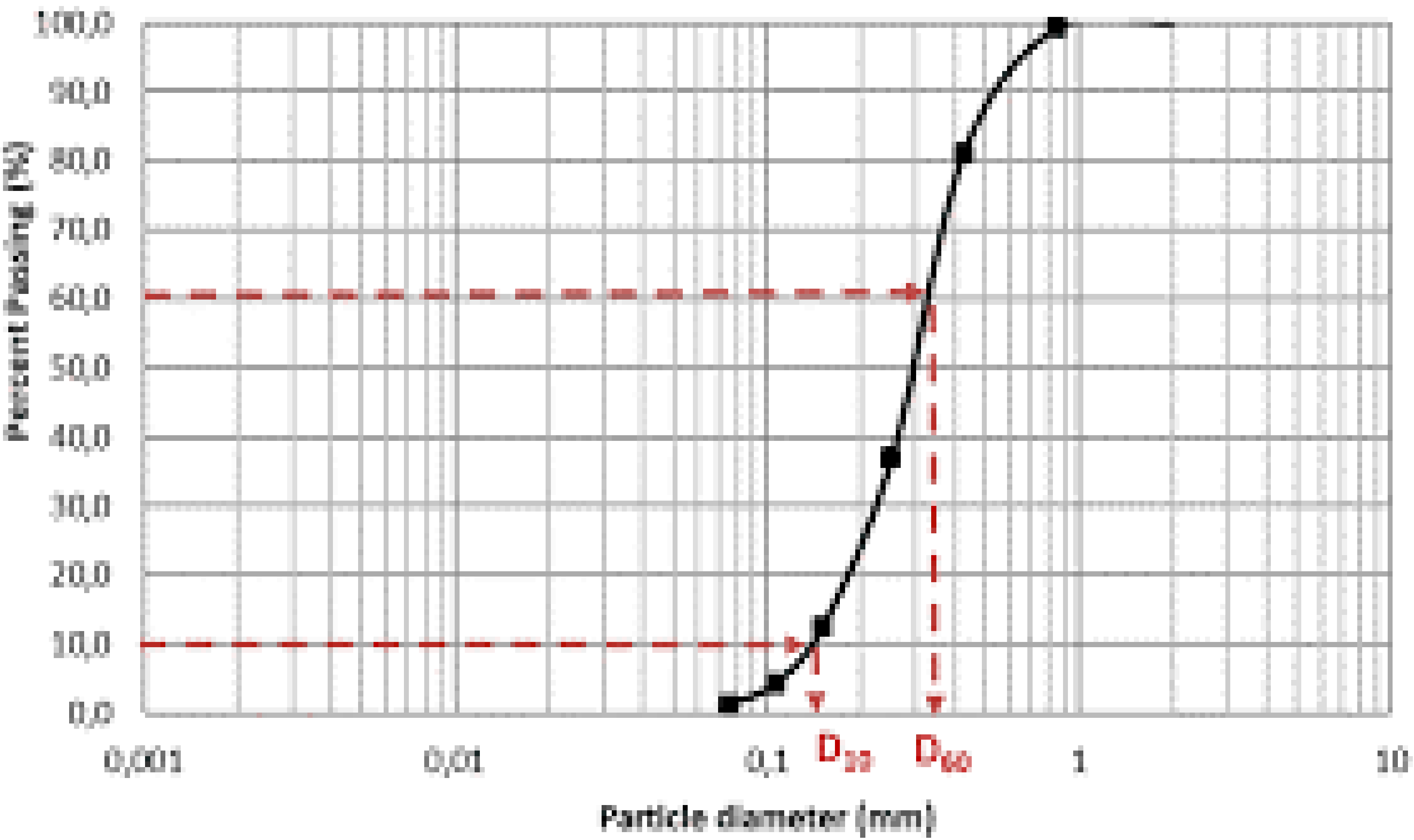
Main Components of a Filter

- **Filter Bed** = Filter sand and is the most critical component of the filter
- **Requirements:** Sand needs to be inert, free from impurities and the sand should be graded
  - On grading, Effective Size (ES) and Uniformity Coefficient (UC) are used
  - ES = Sieve size passing 10% and retaining 90% of the particles
  - UC = Ratio between sieve size passing 60% of particles and that passing 10% of particles

Main Components of a Filter



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Main Components of a Filter

- When UC is close to 1, then the sand is more uniform
- Artificial filter media can have UC=1

Factors affecting Filtration Efficiency

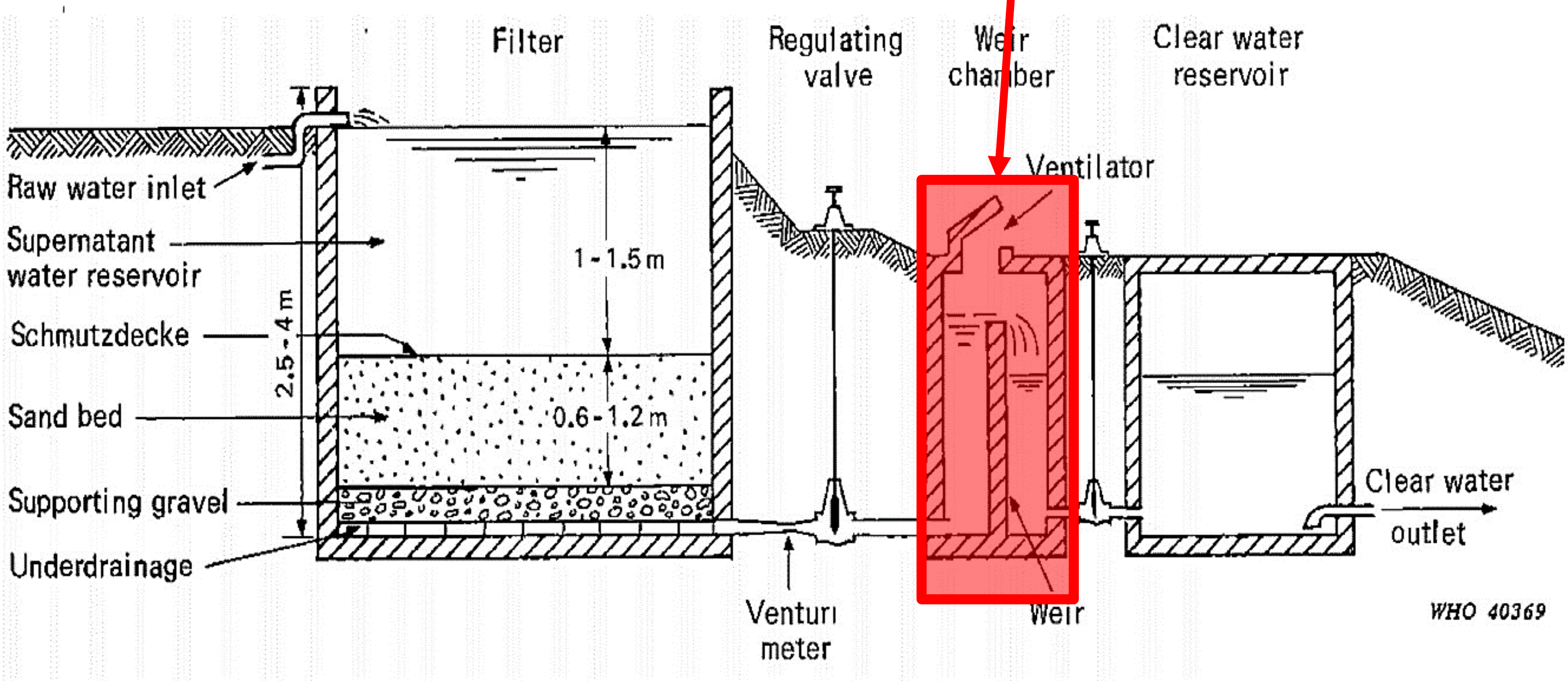
- ❖ Depth of filter bed (Deeper = better quality but low Q and if H>>, construction costs are high)

- ❖ Fineness of filter media (Finer = better quality but =low Q)

- ❖ Rate of filtration (Higher rate = low quality)

SLOW SAND FILTER

Note Level of outlet in relation to sand bed level



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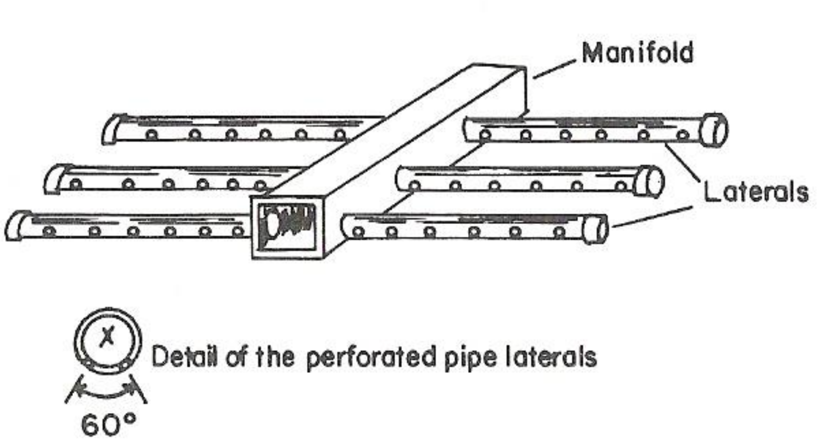
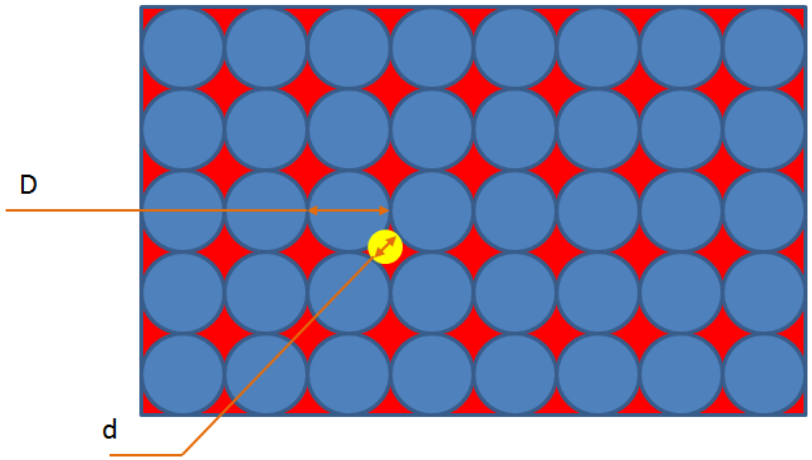
SSF Design Aspects

❖ Under drain



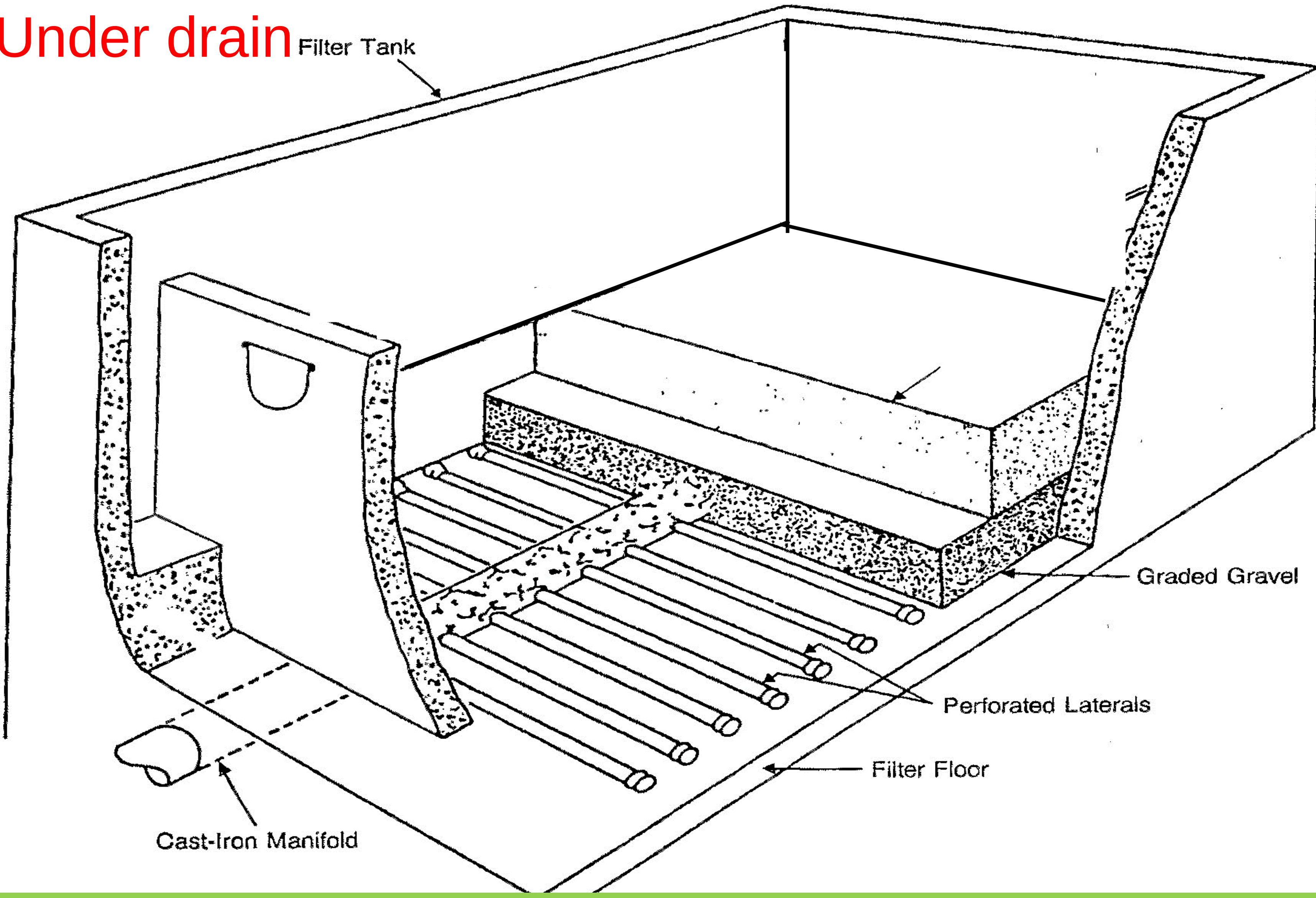


❖ Support gravel: Layered so that the top layer does not "sink" into the supporting layer. e.g.

- 15cm course (EF=10mm)
- 5cm fine (ES=7mm)
- 5cm finer (ES=4mm)

SSF Design

❖ Under drain



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SSF Design Aspects

Eff size = 0.2 - 0.4mm
Uni Coef = 1.7 – 2.5
Depth of Sand Bed = 0.9-1.2m
Head > 1.2m
Filtration Rate (V_f) = 2 – 5m/d

SSF Design Aspects

- Fitration Rate (V_f) is the same as the SLR or Overflow Rate (V_s) in Sedimentation Tank Design. Thus:

- $V_f = Q/A_f$

Where V_f = filtration Rate

Q = flow rate or discharge

A_f = Area of filter

Example:

Design a Slow sand Filter to treat water at a rate of 50 liters per second

SSF Operation

- Filtration rate = 2 to 5m/d
- Due to fineness of sand, most of the treatment is in the first 2 to 3 cm
- Conditioning of the filter (Conditioning period –Lower than normal filtration rates being applied to allow for the development of the Schmutzdecke)
- The Schmutzdecke - film on the surface of the filter
- After reaching the end of the filter run, filter is cleaned manually or mechanically
- Scrapped sand to be washed and reused (Refer to Videos)

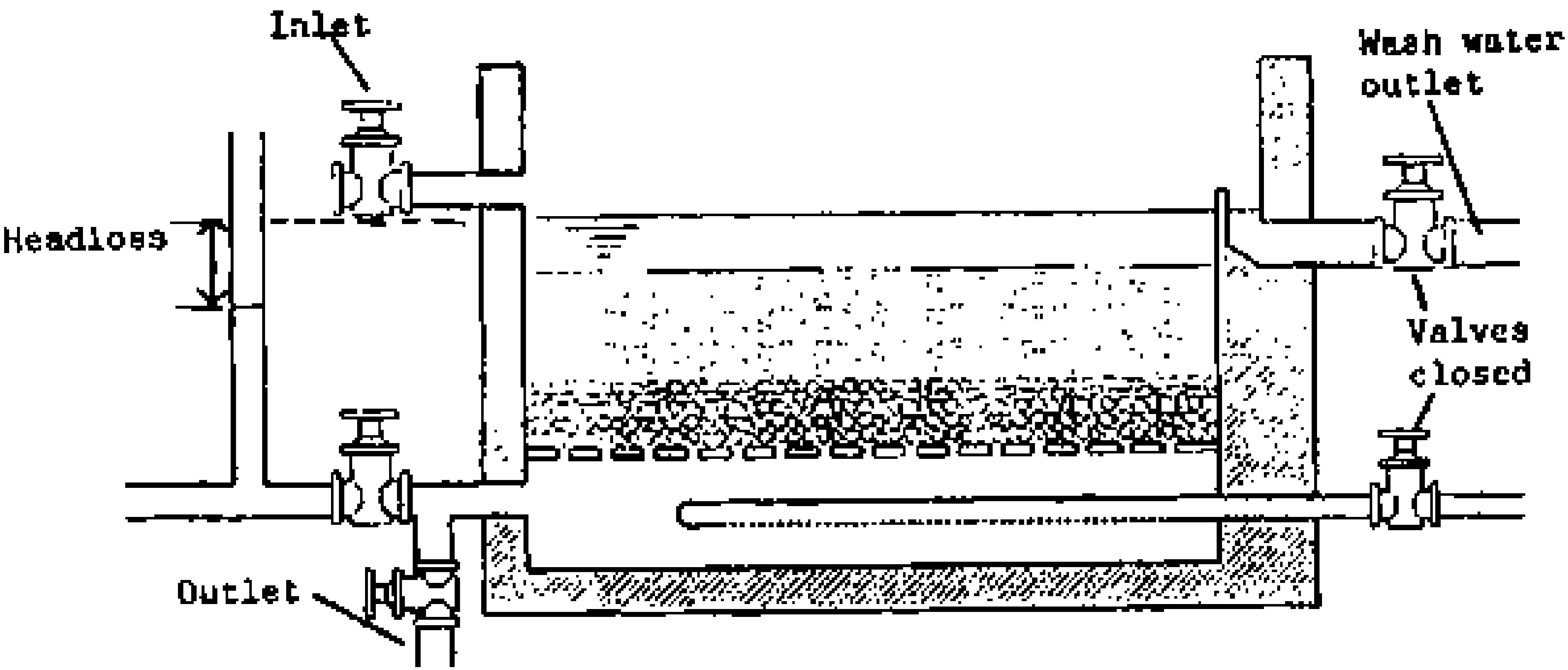
SSF: Advantages and Disadvantages

Simple Design
Cheap to build and operate
No skilled labour required
No electric energy required
High quality of filtrate – Removes Bacteria, viruses and colloids
*Requires large areas

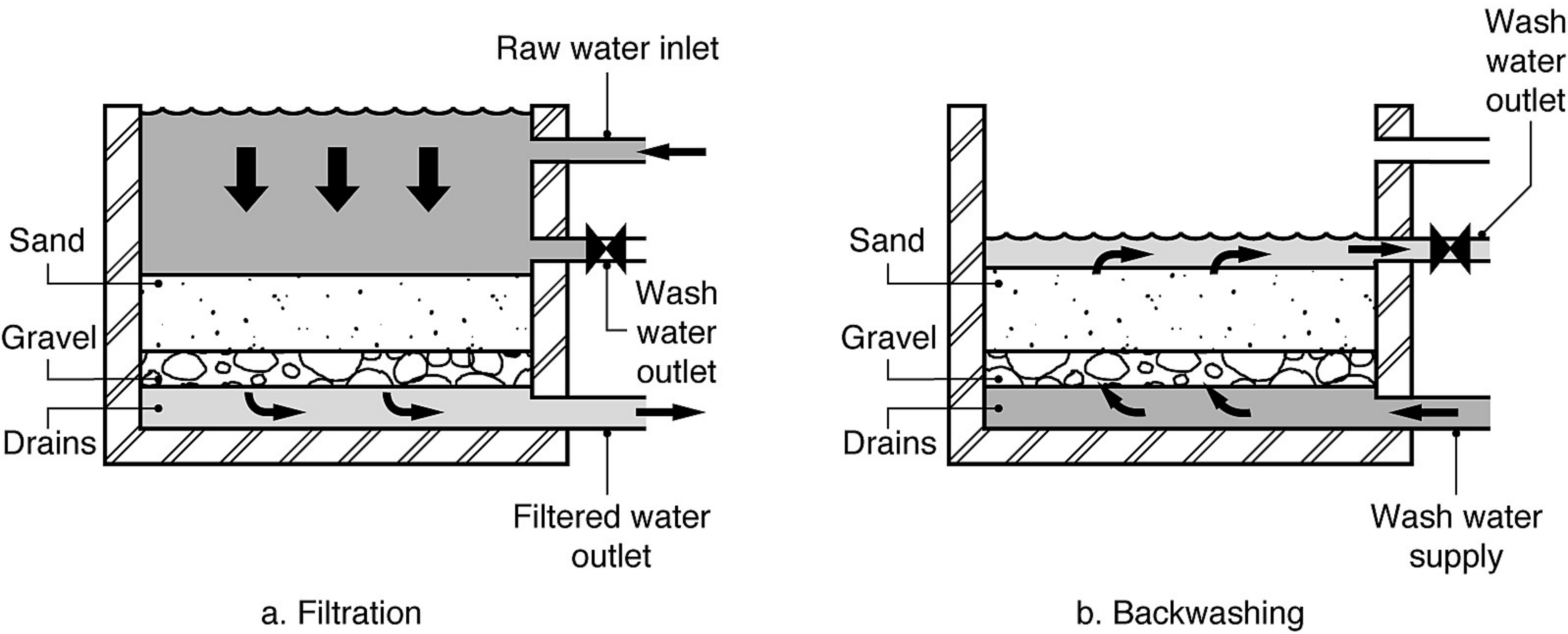
- They work well if influent turbidity is less than 30 NTU

Rapid Sand Filter - Design

- As for Slow Sand Filters but will have a false floor which will accommodate the backwash system



Rapid Sand Filter - Design



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RSF Design

Effective size = 0.5 - 0.7mm
Uniformity Coefficient < 1.8 (Uniform sand required to avoid hydraulic stratification)
Depth of S. Bed = 0.9-1.2m
Head > 1.2m
Rate 5 – 12m/h (120 to 288m/day)

Example:

Design a Rapid Sand Filter to treat water at a rate of 50 liters per second

SSF Operation

- Filtration rate = 120 to 290m/d
- Because of the higher filtration rates, filtration is effected by the whole sand bed
- Hence cleaning is for the whole filter bed and is done through a process called BACKWASHING (Refer to video)

SSF Operation

- Backwashing procedure

1) Lower water level to about 15cm. Close inlet and outlet pipes. Open wash water and run for about 5 minutes to dislodge flocs
2) After 5 minutes, expand bed to attain fluidization through application of compressed air and water until water becomes clear
3) Shut of compressed air but continue applying water to ensure all air bubbles are removed.
4) Start the filtration process

RSF: Disadvantages and advantages

Complex Design
Expensive to build and operate
Requires skilled labour
Requires electric energy
Comparatively low quality of filtrate – Poor removal of Bacteria, viruses and colloids
*Smaller land requirements

SSF and RSF compared

SLOW SAND FILTERS	RAPID SAND FILTERS
Eff size = 0.2 - 0.4mm	Eff size = 0.5 - 0.7mm
Uni Coef = 1.7 – 2.5	Uni Coef < 1.8
Depth of S. Bed = 0.9-1.2m	Depth of S. Bed = 0.9-1.2m
Head > 1.2m	Head > 1.2m
Rate 2 – 5m/d	Rate 5 – 12m/h
Cleaning by Scrapping	Cleaning by backwashing

Basic Filtration Theory

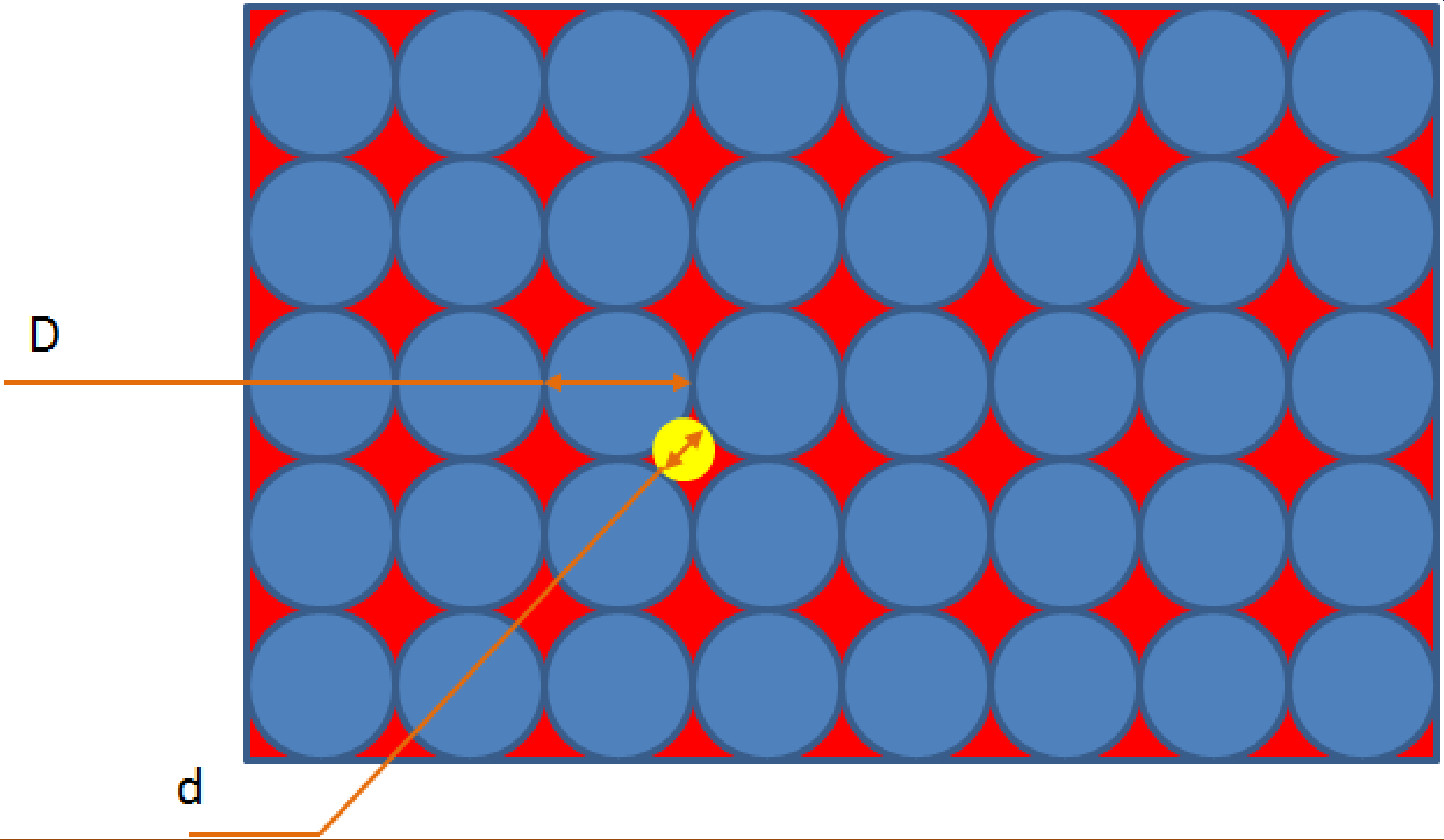
- Filtration is a complex process that involves a number of processes
  - Transportation
  - Attachment and
  - Transformation.
- Under each of these, several processes take place as explained below.

Basic Filtration Theory: Transportation process

Four mechanisms exist under transportation as follows:

- ❖ Screening
- ❖ Sedimentation
- ❖ Interception
- ❖ Hydrodynamic forces

Screening



d = D/6

Removal of particles large than the pore sizes within the filter media. In a filter with grains of uniform sizes, the minimum particle size that can pass through the pores is one sixth of the media size.

Sedimentation

Enhanced in filters as

- ❖ Distance through which particles have to travel is reduced
- ❖ Surface area on which to settle is increased

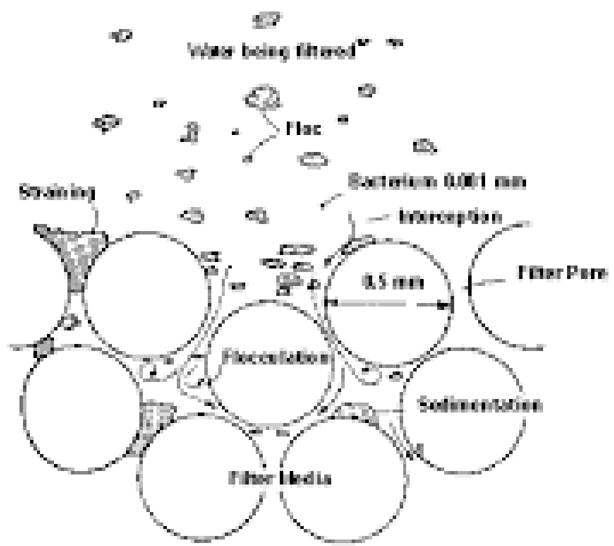
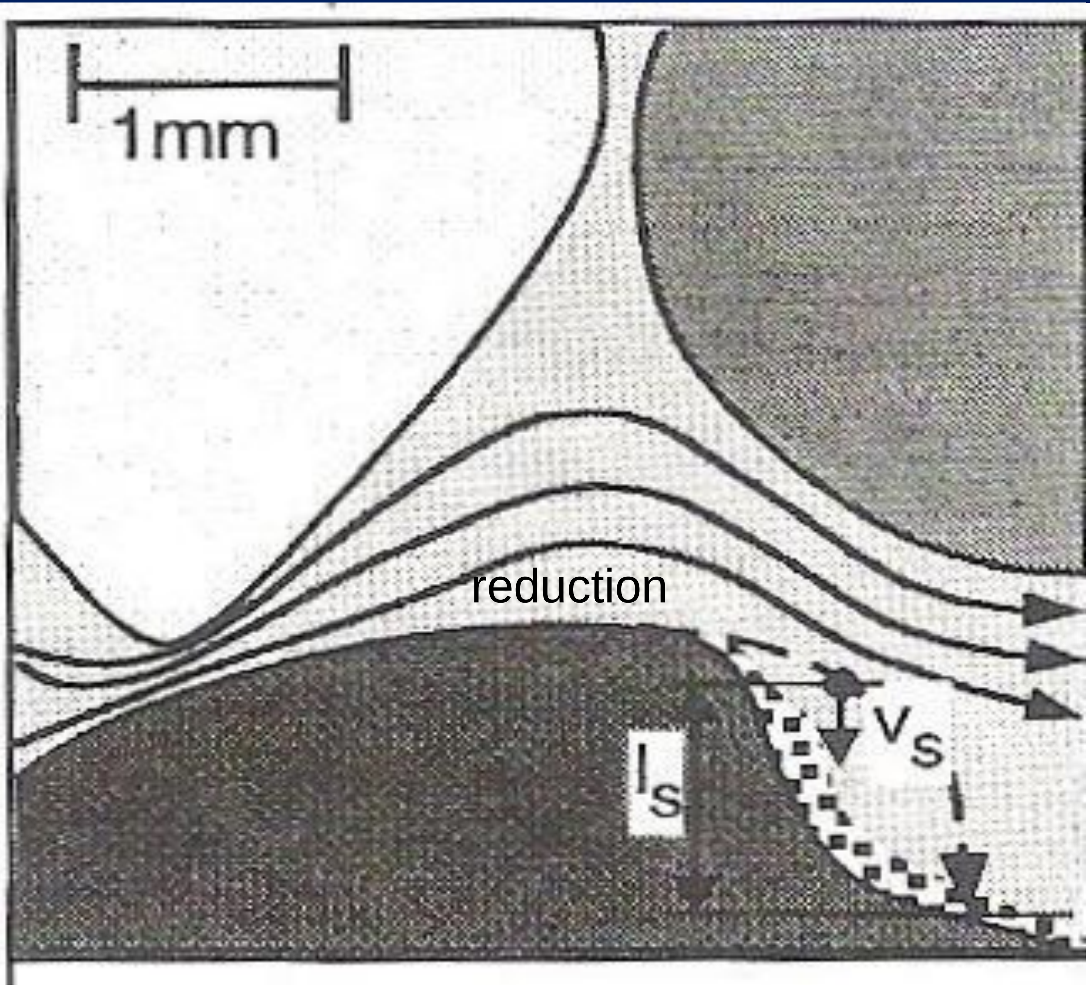


Figure 1. Schematic diagram illustrating straining, flocculation, and sedimentation actions in a granular-media filter.

Interception

❖ Interception: The process which enhances particle removal through gradual reduction of the pore size caused by accumulated material (Partly reason why quality improves as we approach end of filter run)

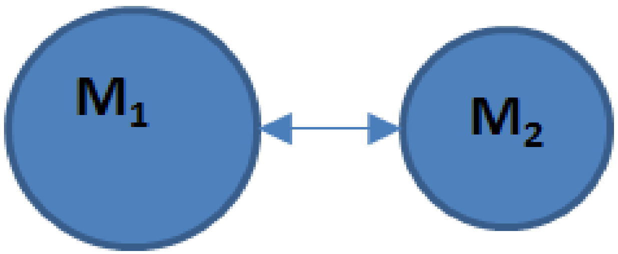
Hydrodynamic forces



❖ Flow patterns within the media are curved and may result in the "throwing" off of particles from the water

Filtration: Attachment mechanism

- **Mass attraction and electrostatic forces:** -_A combination of these forces is frequently called adsorption. These forces enable particles to keep in contact with other solids and the filter media.



$$F=G*M_1*M_2/d^2$$

- **Biological activity:** Associated with particles of organic origin when they are deposited on the media. These substances will form a sticky and slimy layer around the media which can enhance the attachment process.

Filtration: Transformation Mechanisms

- Usually through biochemical oxidation of the attached organic matter to end up with carbon dioxide, water and some inorganic salts.

- This process usually occurs in slow sand filters where the filter runs are longer.

Filtration type versus treatment mechanisms

- SS Filtration (all discussed mechanisms apply)
- RS Filtration (predominantly only transportation)
- Conclusion: Slow sand filtration is more superior in terms of quality

END OF SEDIMENTATION AND FILTRATION

THANK YOU