CHAPTER FOUR:

- ✓ **Impurities of water**
- ✓ **Small scale (household) water treatment**
- ✓ **Municipality water treatment**
- ✓ **Advanced water treatment**

IMPURITIES OF WATER

- **Pure water** is not found under natural conditions.
  - That water which is nearer to purity is **rain water** especially that which has been collected from clean surfaces and that which is stored in a tank protected from pollution or contamination.
  - **Even then rainwater may pick various kinds of impurities while falling**

i. Types of impurities

1. **Organic impurities-** found from the growth and decay of animals and vegetable matters.
   - ✓This may include waste matter (animal, human) refuse and garbage, bacteria, microscopic plants and animals.

2. **Inorganic impurities**-found from the earth.
   - ✓This are minerals/nutrient and chemicals

ii. Forms of Impurities of water

1. Suspended impurities (> 1 μm)

- Very fine particles of insoluble matter, which **float in a liquid**;
- They **do not disappear** as in the case of dissolved solids.
- If they are allowed to stand undisturbed they may **settle to the bottom**.

➢Some of these are:

a) ***microorganisms (1-10* μm**)as a result of pollution of surface water. Pathogens (harmful bacteria) may be present in such condition, most dangerous impurity.

Impurities of water…

b) Suspended solids that include ***solids and clay, pesticide, insecticides,*** that may be washed down from agricultural or industrial setup or ***droplet*** from a sprayer.

- Suspended solids (ferric hydroxide) generally cause taste or color or turbidity (muddiness)

c) ***Algae*** that grow in ponds, riverbanks and in still water, causes taste, color and turbidity

Impurities of water…

2. Dissolved impurities (< 0.001 μm)

- Many solids and gasses are soluble in water. Thus, if they are put in water they disappear seemingly to become liquids, but in reality they are there dissolved.
  - **These are divided in to two**: **Gases** (for example-oxygen, CO_2, H_2S,etc) and **Minerals/ions** (Salts of Ca & Mg that causes *hardness* in water and Na & K causes *alkalinity*; other minerals such as Pb, As, Hg, Cr are *toxic* and Fluoride, cause *florosis* and *stained teeth*; Nitrate causes *Blue baby syndrome or Methaemoglobin anemia* in infants;
  - Humic substance – causes color and test problem

Impurities of water…

3. Colloidal impurities (0.001- 1 μm) or (0.005 – 0.2 μm)

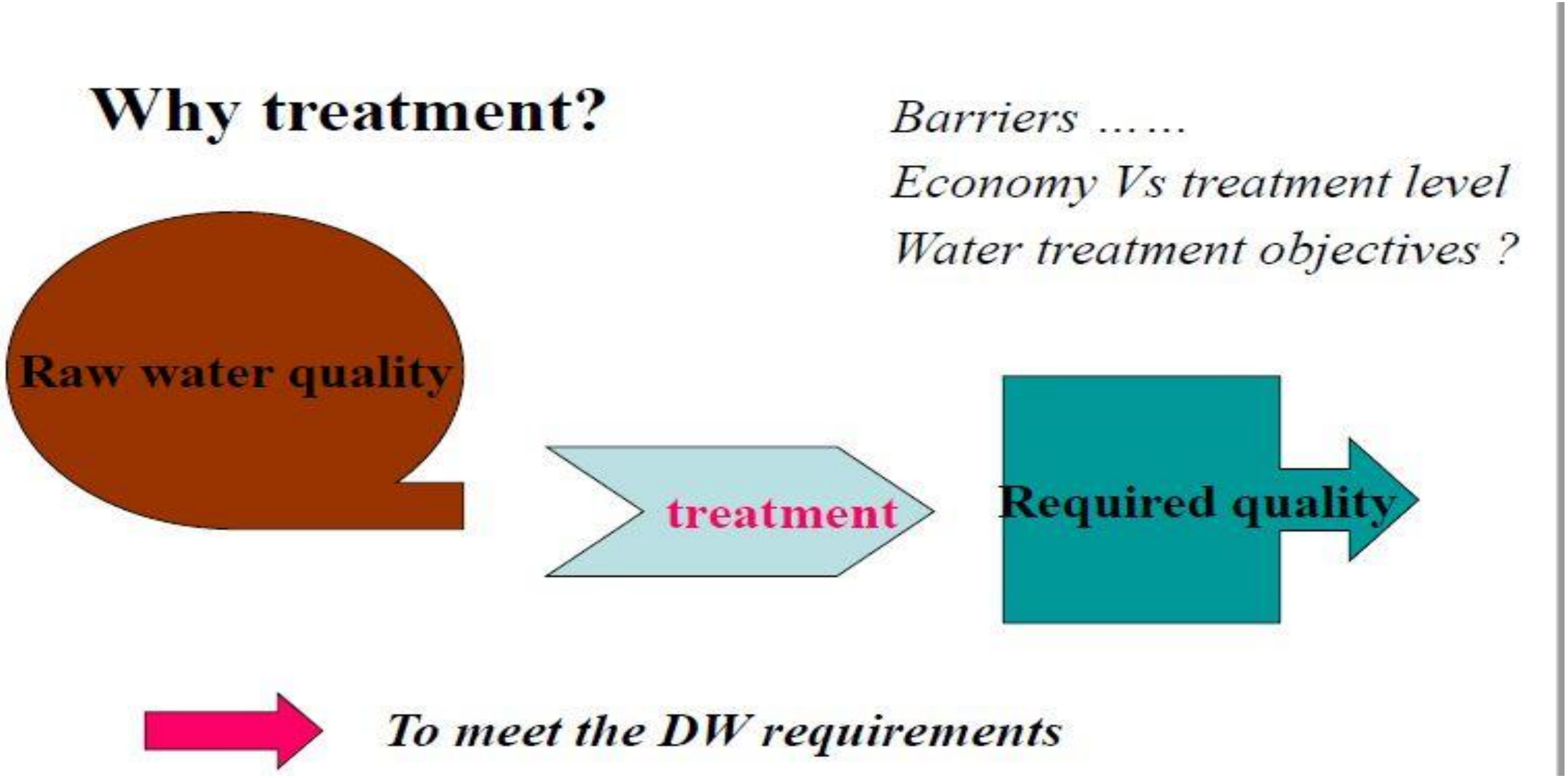
- Colloidal particles (colloids) are midway in size between dissolved solids and suspended matter.
- Colloids are **kept in suspension** (stabilized) by electrostatic repulsion and hydration.
  - ✓ Some of these are: clay, proteins, silica, microorganisms (0.03 – 0.3 μm), great variety of organic polymers, cause color and test problems

Impurities of water…

- Some impurities of water **cannot be seen with the naked eye** but can be detected by test or odor.
  - Some can be seen, and other can be detected only by laboratory tests.
- Therefore it is usually advisable to ascertain the nature and quality of impurities by **taking samples at different seasons and condition to the laboratory**.

WATER TREATMENT PROCESS

Water treatment processes overview



Why treatment?

Barriers ……

Economy Vs treatment level

Water treatment objectives ?

Raw water quality

treatment

Required quality

To meet the DW requirements

How to reduce the sanitary risks from drinking water ?

- Applying **different barriers is important** to reduce the sanitary risk from drinking water due to physical, microbial and chemical contaminants.
- **Barriers** include:
    - ✓**Watershed and land use management** to protect surface and ground water;
    - ✓**Selection and protection** of the best available water sources;
    - ✓**On-site waste water treatment** and reuse;

How to reduce the sanitary risks ….

- Barriers include:
  - ✓Adequate and well maintained **distribution systems**;
  - ✓Safe water practices by **consumers**; and
  - ✓**Water treatment (WT)**

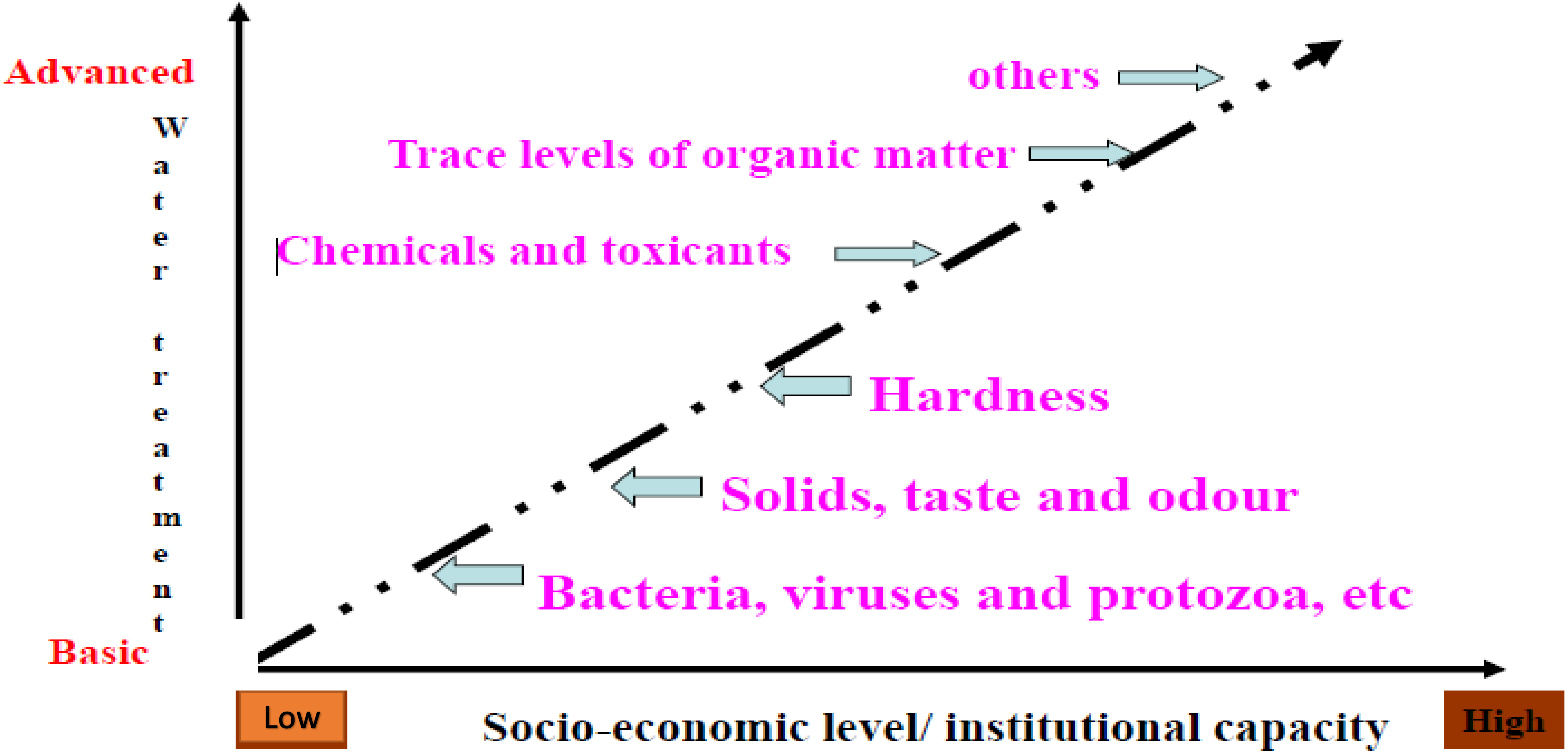
- Application of a **multiple barriers strategy** should significantly reducing the cost and complexity of water treatment.

Conceptual relation between **socio-economic level and water treatment technologies**

- The **level of water treatment technology** should be in harmony with:
  - ✓The type of risk existing in the supply sources **= suitable source selection**
  - ✓Institutional and socio-economic conditions prevailing in the target community **= affordability**
  - ✓Availability of skilled operation & maintenance, and management staff **= technical complexity**

- With increasing life expectancy, enhanced institutional capacities and improve economic conditions, **water treatment has progressively combined technologies** to reduce initially the acute health risks, often of **microbiological nature**, and later the chronic health risks, usually of **physical**, **chemical** origin.

Schematize conceptual relation between socio-economic level and water treatment objectives



Advanced

Water treatment

Basic

others

Trace levels of organic matter

Chemicals and toxicants

Hardness

Solids, taste and odour

Bacteria, viruses and protozoa, etc

Low

Socio-economic level/ institutional capacity

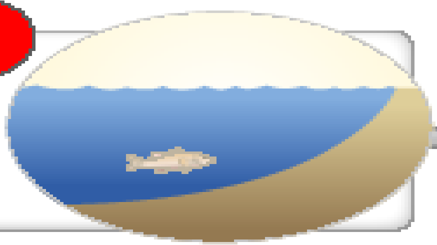
High

- Water treatment: Is the process **removing all unwanted substance**.
- **Major Objectives:**
  - **To prevent water born disease;**
  - **To remove substance which imparts;**
  - **To remove excess minerals;**
  - **To regulate essential chemicals;**
  - **To remove excess dissolved gasses.**

1

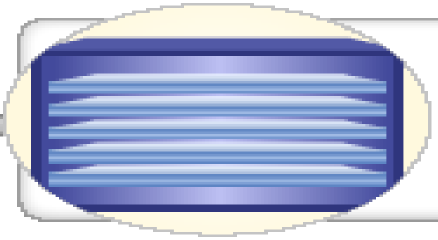
Water Intakes

Untreated water flows into intake cribs and through intake pipes as far as 2 km offshore. The intake cribs are equipped with a chlorine solution, diffused for Zebra Mussel control.



2

Intake Screens

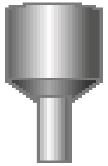


Mechanically cleaned traveling screens remove large objects and debris, such as leaves, sticks, and occasionally fish from the raw water.

3

Pre-chlorination

Chlorine is added to the raw water to kill most disease causing micro-organisms and help control taste and odour causing substances.



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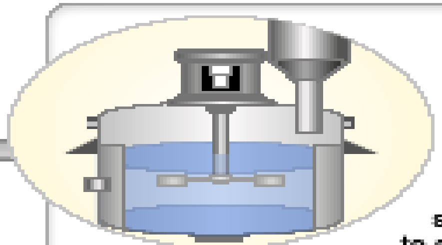
Flash Mixing

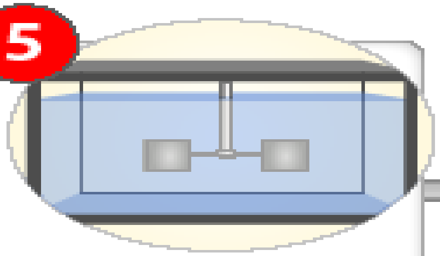


Alum is added to fast-stirring flash mixers which cause very fine particles (such as silt), that would not readily settle out of the water, to clump together into larger particles called floc.

5

Coagulation-Flocculation

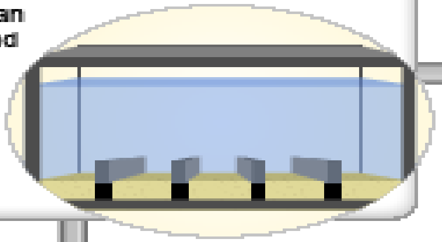
The flocculation basin gently agitates the water to concentrate the suspended solids in an efficient manner. Additional chemicals may be added to the flocculation process either upstream of the flash mixers or as a part of the coagulation-flocculation process, including: powdered activated carbon (for taste and odour control); polymers (as coagulant aids); caustic soda (for pH adjustment); or chlorine (for disinfection).



6

Sedimentation

In the settling tanks, the speed of the flowing water is slowed down so that the larger suspended particles can settle out by gravity and collect on the tank bottom. The clean water on the surface then spills over the top of the tank, on-route to the filters.



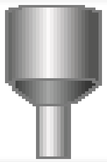
7

Filtration

Filtration is the final step in removing the particulate matter. Layers of gravel, sand, and anthracite filter out the remaining suspended particles, including fine pieces of floc, algae, silt, and other impurities. When a filter accumulates too many solids it is taken out of service and backwashed.

8

Post-chlorination

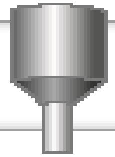


Chlorine is added to the water to kill any remaining disease causing organisms and to sustain a chlorine residual in the water as it makes its way through the distribution system.

9

Fluoridation

At the Elgin Water Treatment Facility, fluoride is added to help prevent cavities.



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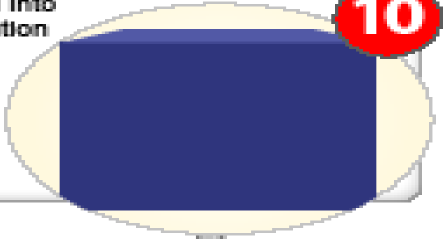
Clear Well

With the treatment process complete, the purified water collects in a clear well below the filters and is stored before being discharged into the distribution system.



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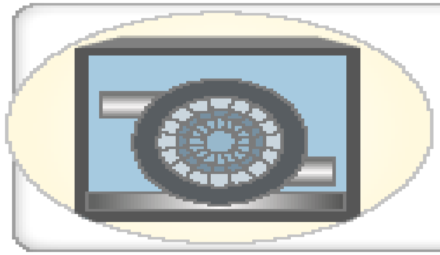
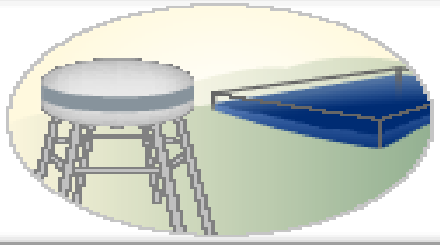
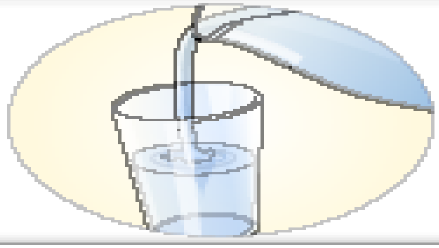






Distribution

High lift pumps distribute the treated water through transmission mains to reservoirs, pumping stations, and consumers. Throughout the system, water is tested regularly to ensure high quality.

Table 1: General effectiveness of conventional water treatment processes for contaminant removal

Water Quality Parameters	Treatment processes					
	Aeration					
	Sedimentation (Sedm)	coagulation	Flocculation, Sedm + RSF	SSF	Multistage Filtration	Disinfection
Bacteria	0	0	+++	+++	++++	++++
Viruses	0	0	+++	+++	++++	++++
Giardia cysts	0	0	+++	+++	++++	++
Cryptosporidium oocysts	0	0	+++	+++	+++	+
Turbidity	0	+	++++	+++	++++	0
Suspended solids	0	+++	++++	+++	++++	0
Taste and odour	++	0	+++	++	+++	+

0 = no effect; ++++ = increasing positive effect; -- = negative effect

Water Quality Parameters	Treatment processes					
	Aeration					
	Sedimentation (Sedm)	coagulation	Flocculation, Sedm + RSF	SSF	Multistage Filtration	Disinfection
Iron and manganese	++	+	+++	+++	+++	++
Fluoride	0	0	+	0	0	0
Arsenic	0	0	++	+	+	0
Heavy metals	++	0	++	+	++	+
Dissolved oxygen	+	0	0	–	–	0
Carbon dioxide	-	0	0	+	+	0
Color and organic	0	0	++	++	++	+

0 = no effect; ++++ = increasing positive effect; -- = negative effect

Table 2: Groundwater treatment processes

Water Quality Parameters	Treatment processes					
	Aeration for					
	Increasing 0_2	Reducing CO_2	Plain Sedimentation	Rapid) Filtration	Safety Disinfection (Chlorination)	
Aerobic, fairly hard and not corrosive					0	
Aerobic, soft, and corrosive		X			0	
Anaerobic, Fairly hard, and not corrosive	X				0	

X, necessary; 0, optional

Table 2: …

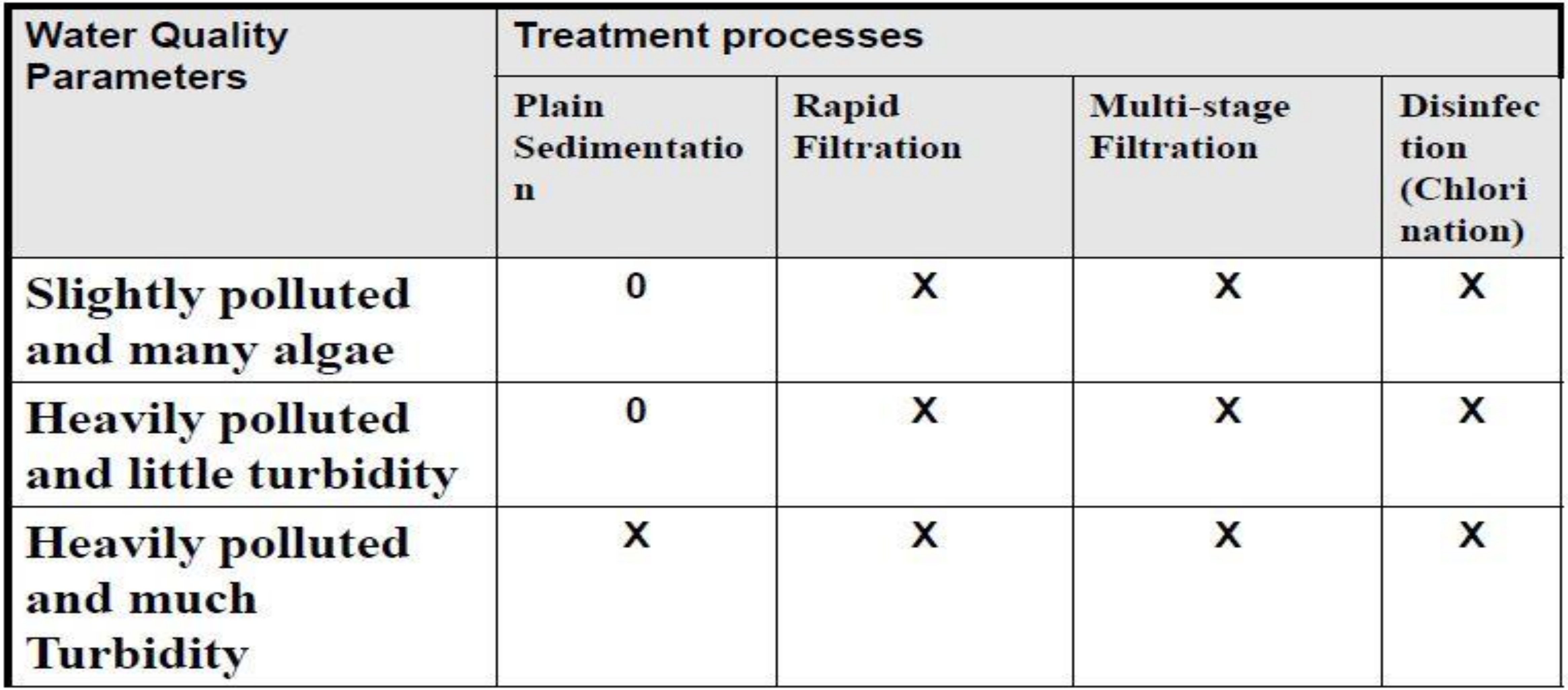
Water quality parameters	Treatment process				
	Aeration for				
	Increasing O2	Reducing CO2	Plain sedimentation	Rapid filtration	Safety Disinfection (chlorination)
Anaerobic, fairly hard, not corrosive with iron and manganese	X		0	X	0
Anaerobic Soft, corrosive no iron and manganese	X	X			0
Anaerobic, Soft corrosive with iron and manganese	X	X	0	X	0

X, necessary; 0, optional

Table 3: Surface water treatment processes

Water Quality Parameters	Treatment processes			
	Plain Sedimentation	Rapid Filtration	Multi-stage Filtration	Disinfection (Chlorination)
Clear and Unpolluted			0	0
Slightly polluted and low turbidity		X	X	X
Slightly polluted and medium Turbidity	0	X	X	X
Slightly polluted and high turbidity	X	X	X	X

X, necessary; 0, optional



Water Quality Parameters	Treatment processes			
	Plain Sedimentation	Rapid Filtration	Multi-stage Filtration	Disinfection (Chlorination)
Slightly polluted and many algae	0	X	X	X
Heavily polluted and little turbidity	0	X	X	X
Heavily polluted and much Turbidity	X	X	X	X

X, necessary; 0, optional

Section 1: Small scale water treatment

When it needs to have water treatment at small scale?

- Emergency situations
- Temporary settlement areas
- At household level and
- In areas where the municipality is not well organized

Methods, used singly or in combination, depending on the reliability of each method.

1. Boiling
2. Filtration
3. Solar disinfection
4. Chemical disinfection and
5. Households Water Storage

1. Boiling

- reliable methods of disinfecting water at households level
- water is brought to the boiling point and is kept boiling for **15 to 20 minutes**
- all forms of **MOs will be destroyed**
- boiling is effective **for all kinds of raw water**

Dis:

- flat taste
- care must be taken to avoid recontamination

2. Filtration

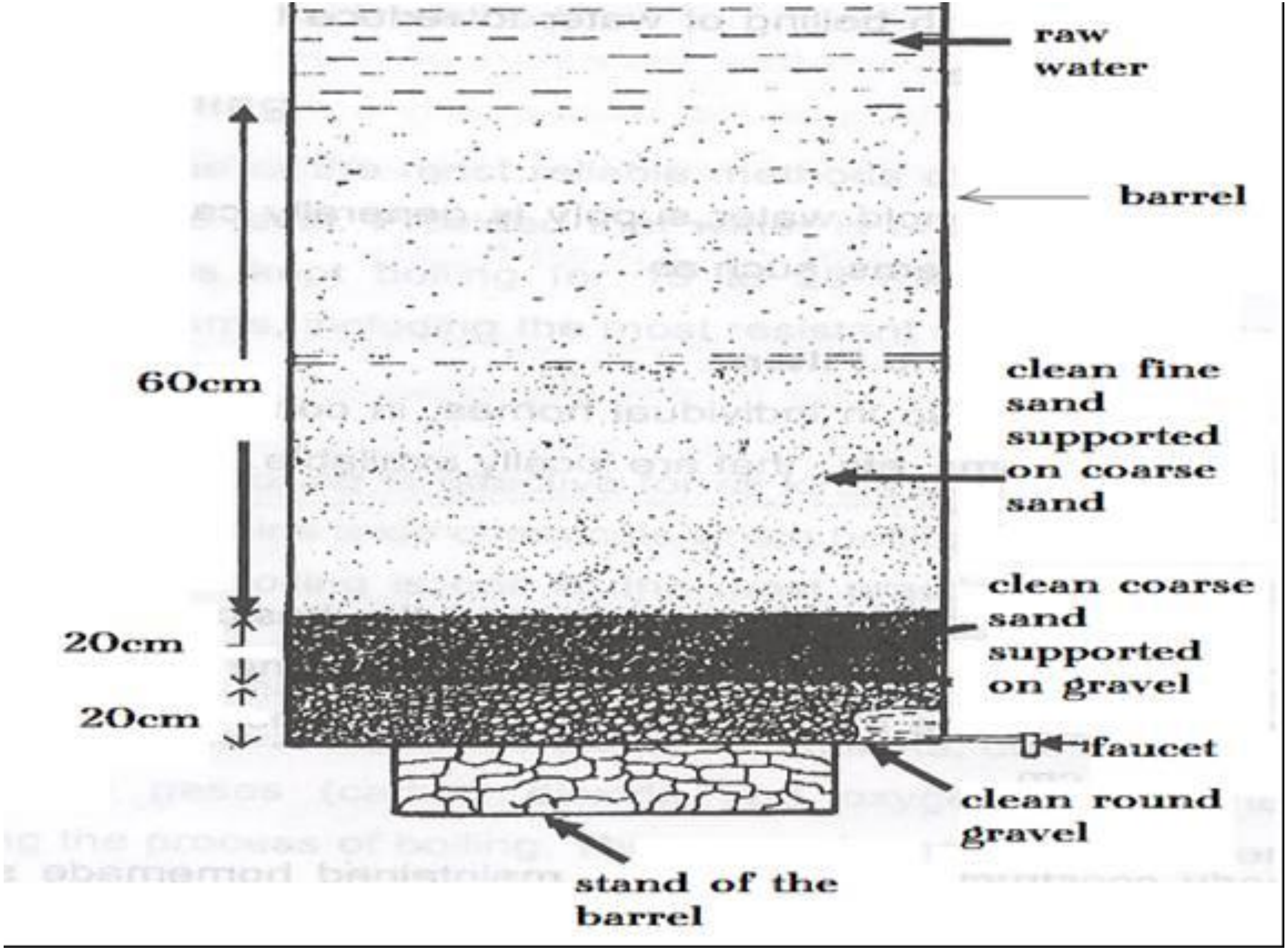
- Its simple filtration systems

A. Homemade sand filters

- in containers such as steel barrels, drums, etc

- depth of filter sand should **not be less than 60 cm**

- Can remove: =>
  - **turbidity**
  - **taste and odor**
  - **cysts and ova of parasites** and
  - **other relatively larger organisms**.


raw water
barrel
60cm
clean fine sand supported on coarse sand
20cm
clean coarse sand supported on gravel
20cm
faucet
clean round gravel
stand of the barrel

Some of the **limitations** of a homemade sand filter are:-

- It cannot be relied upon to remove of **viruses** and some of the **very small-sized bacteria**
- It frequently gets **clogged**, particularly if the raw water to be filtered is **turbid**.

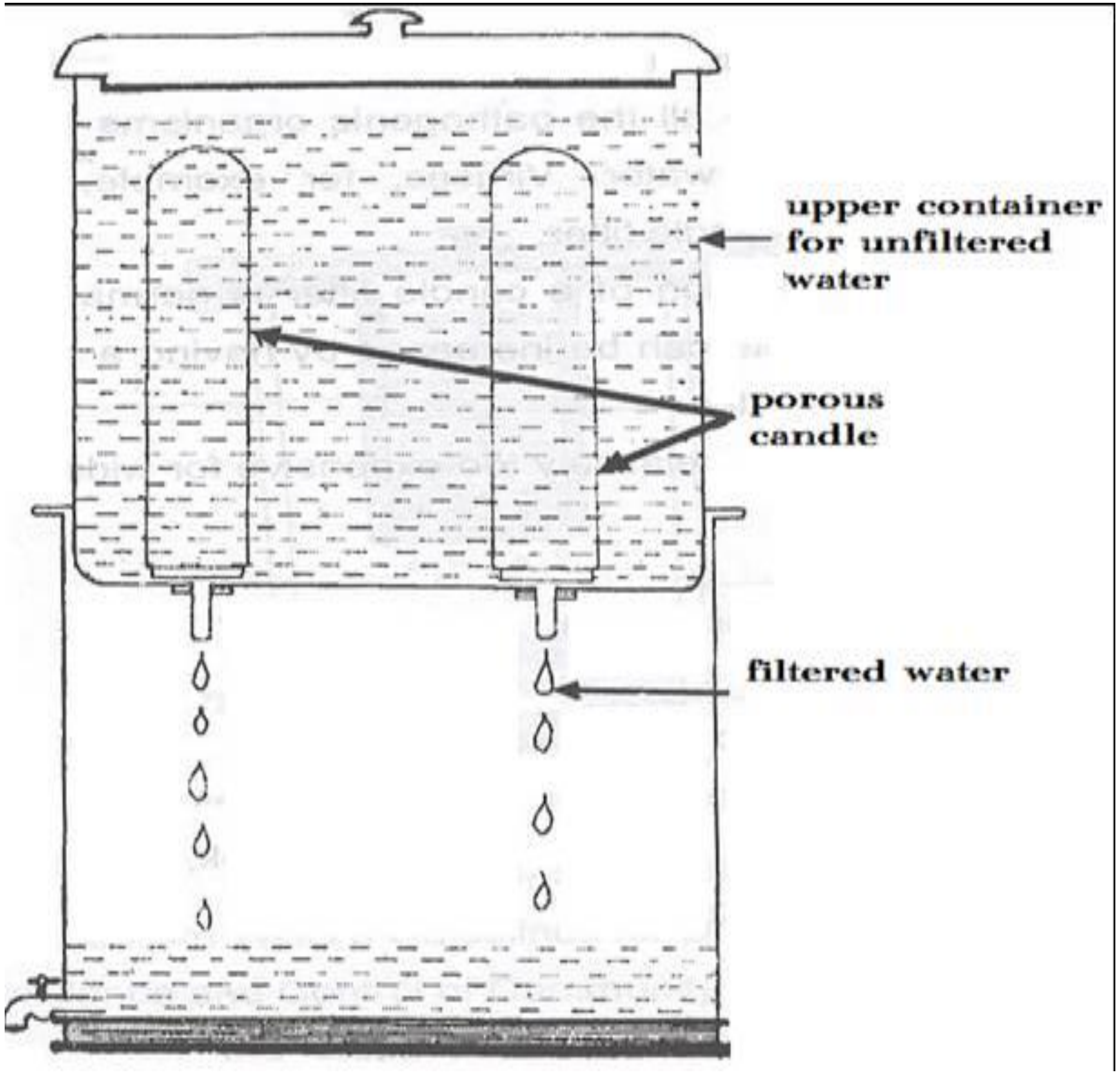
Maintenance of a homemade sand filter

- There must be a **continuous flow of raw water** over the filter bed

- The rate of filtration should normally be controlled not to be more than **1.5 liters per minute**.
  - This rate will be achieved after the filter has been in operation for a few days.

- The top-most layer of the sand must be **scraped off, cleaned and replaced at fixed periods.**

B. Home candle filters



- The core of the filter is a porous cylinder

- commercially made
- various types and sizes,
- 0.3 micron-50 microns

Some of the limitations of candle filters

- The average size of a bacterium is about **1.5 microns**.
  - Thus, may **not remove all the pathogenic organisms**
  - Viruses, for example, cannot be removed by a candle filter.

- The **rate of filtration** of a candle filter is normally very low
  - the rate can be increased by having a three-candle or four-candle

- Candle filters are relatively **too expensive** for wide use by the general public.

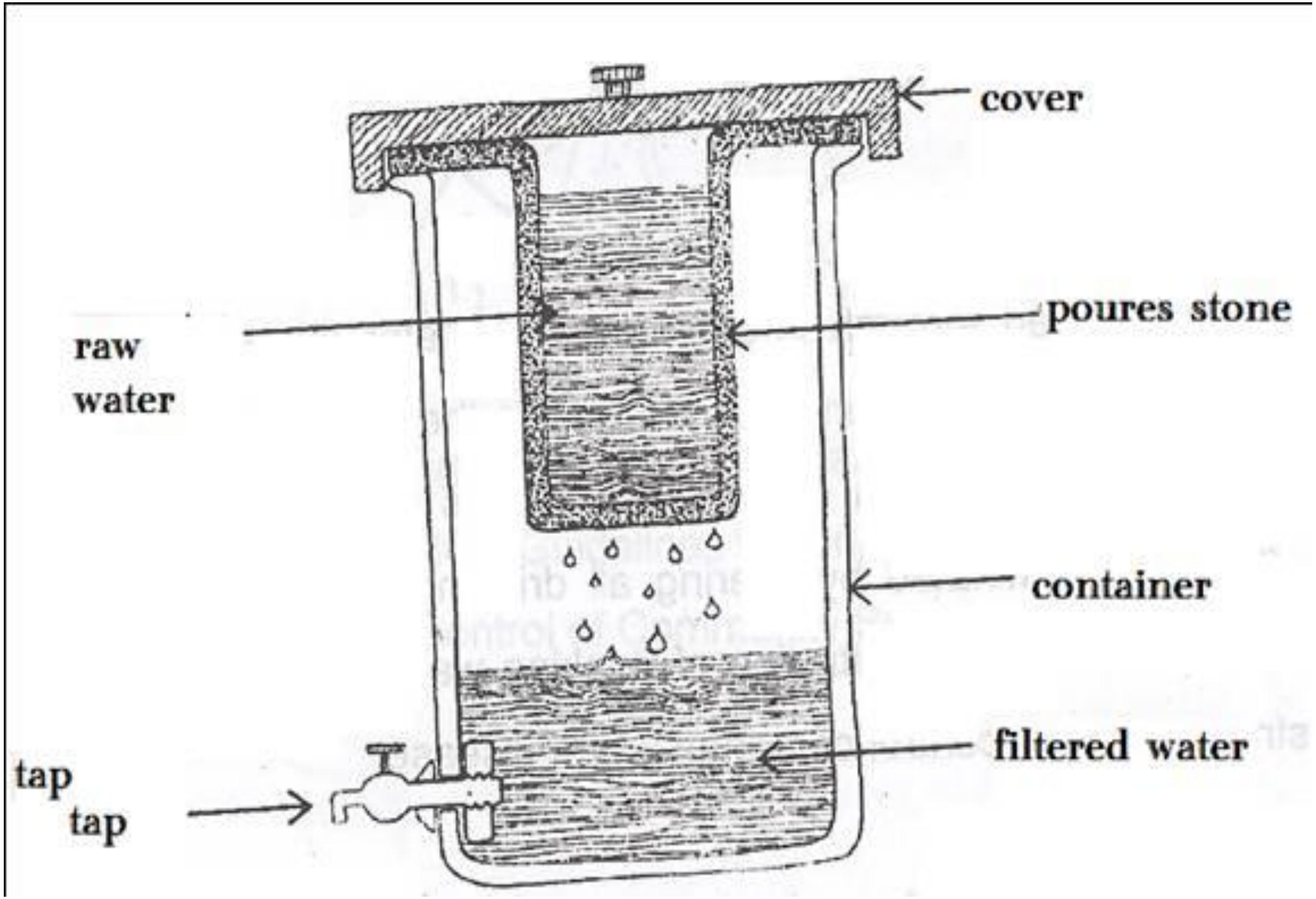
Maintenance during operation

- The raw water to be filtered must be reasonably clear
  - to reduce clogging of the candle pores

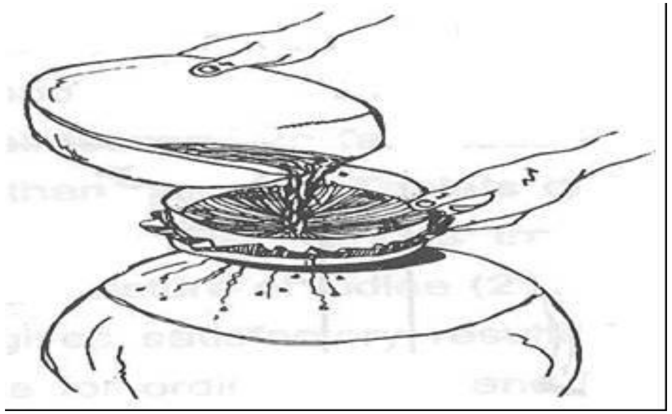
- The candle needs dismantling once a week, for washing and sterilizing in boiling water.

C. Stone filters

- Stone filters are **similar to candle filters**
  - but are carved from **porous local stone**
- They are generally difficult to **clean** and **heavy to lift,**
- relatively **inexpensive** if they can be produced locally
- This method of filtration could be possible in Ethiopia using the **local "Beha" stone**.


cover
poures stone
raw
water
container
filtered water
tap
tap

D. Cloth filtration to prevent Guinea Worm Disease

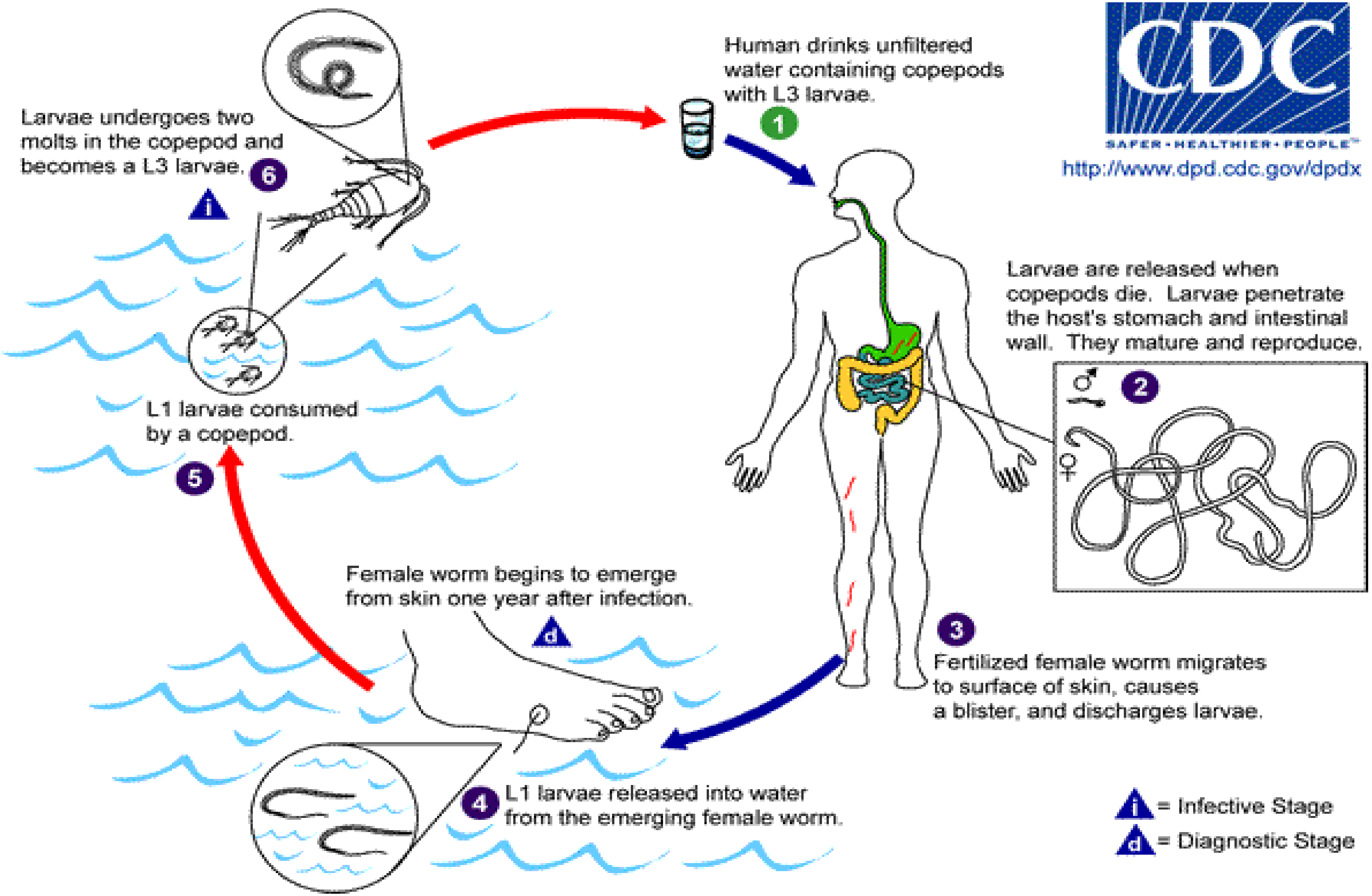


- Guinea-worm disease (dracuncuiliasis) is transmitted via contaminated drinking water

- Filtration of drinking water is thus a primary strategy for the control of guinea-worm disease.

- Filters should be of **mesh size less than 130 μm**; this should remove all infected intermediate hosts

Infection Cycle of Guinea Worm



1 Human drinks unfiltered water containing copepods with L3 larvae.

2 Larvae are released when copepods die. Larvae penetrate the host's stomach and intestinal wall. They mature and reproduce.

3 Fertilized female worm migrates to surface of skin, causes a blister, and discharges larvae.

Female worm begins to emerge from skin one year after infection.

4 L1 larvae released into water from the emerging female worm.

5 L1 larvae consumed by a copepod.

6 Larvae undergoes two molts in the copepod and becomes a L3 larvae.

i = Infective Stage

d = Diagnostic Stage

3. Solar disinfection (SODIS)

- SODIS is performed by beaming sunshine onto transparent water containers with exposure times of several hours

What procedure we need to follow in SODIS?

Use clean PET bottles

Fill bottles with water, and close the cap

Expose bottles to direct sunlight for at least 6 hours (or for two days under very cloudy conditions)

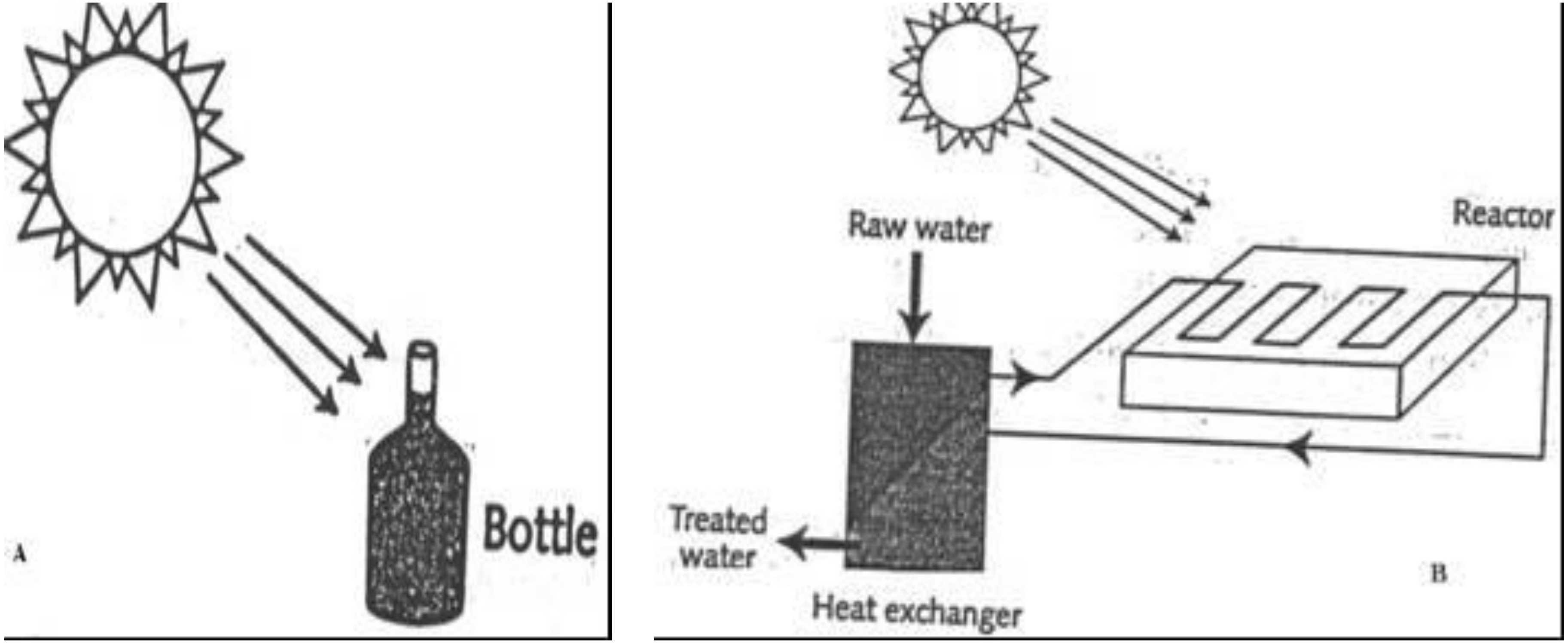
Store water in the SODIS bottles

Drink SODIS water directly from the bottles, or from clean cups

- PET (*Polyethylene terephthalate)* bottle
- For oxygen saturation, bottles can be filled three quarters, then shaken for 20 seconds (with the cap on), then filled completely.

Types of disinfection systems in SODIS

- There are two types of disinfection systems such as the **batch and continuous**



The continuous one comprises an exposure vessel or reactor and a tank where treated **water exchanges heat with raw water** (obviously with out mixing).

4. Chemical Disinfection

A. Chlorine or its Compounds

- Usually disaster strikes an area,

Two suggestions

- population **never prepare** their own stock solutions from high concentration hypochlorite.
- ideal stock solution to be used in emergency situations is the one holding a concentration of **5000 mg of active chlorine/liter**.

How to prepare stock solutions?

$$W_{product} = \frac{(V_{water} X C_{stock})}{(C_{product} X 10)}$$

Where:

- **V $_{water}$** = Volume of stock solution will be prepared, in liters

- **C $_{stock}$** = concentration of stock solution intended (if as suggested, it is intended a 5000 mg/l concentration, then the value for C $_{stock}$ should be = 5000)

- **C $_{product}$** = Chlorine concentration in the product as specified by the manufacturer (in the formula, only the number should be placed, for example 65 when the chlorine concentration in the products is 65%)
- **10** = Factor in order that the result be given in grams of the product

- 5 mg/l the disinfection dose that will be suggested to the population should be in the moments of the extreme emergency

- 2 mg/l under less stressing conditions

- The minimum contact time should be 30 minutes.

Appropriate dilutions with stock solution

Volume of water to disinfect (liters)	Volume of stock solution (of 5000 mg/l) to add for a 5 mg/l final concentration	volume of stock solution (of 500 mg/l) to add for a 2 mg/l fina concentration
1	20 drops = 1 ml	8 drops
5	100 drops = 5 ml	40 drops = 2 ml
10	10 ml	4 ml
20	20 ml	8 ml
100	100 ml	40 ml
200	200 ml	80 ml
1000	1 liter	400 ml

B. Iodine and its Compounds

- have also been effectively used for individual water disinfection

- Iodine is believed to be a **better disinfectant than chlorine**

- **Tablets of iodine** are available under various trade names (**Globaline**, **Potable Aqua**, etc).

Dis:

- is relatively **expensive** for ordinary use

- Iodine **sensitive ppl**

5. Households Water Storage

- **turbidity** will be reduced
- **bacteria and eggs of parasites** will be sediment

- The principal health risk associated with household water storage is the **ease of recontamination during transport and storage,** particularly if the members of a family or community do not all follow good hygiene practices.

Peer Group discussion-two need to be submitted in paper

✍ How raw water is made safe to drink in your community/household in small scale levels?

✍ To avoid recontamination of drinking water in the household, what good hygiene practices needs to follow?

Good hygienic measures include the following:

- Careful storage of household water and regular cleaning of all household water storage facilities.
- Construction, proper use, and maintenance of latrines;
- Regular hand-washing, especially after defecation and before eating or preparing food;
- Careful storage and preparation of food.
- Water that is clean from the supply or has been treated in the household needs to be protected from recontamination.

The most important elements of water storage can be summarized as follows:-

- Use a clean water source or treat the water, either at home or in a storage tank.
- Store water in an earthenware or plastic container with a cover.
- Store the water container at a height that puts it beyond the reach of children and animals.
- Fit a tap to the container for drawing clean water in order to prevent contamination by dirty cups, ladles, or hands.

Section 2: Conventional water treatment

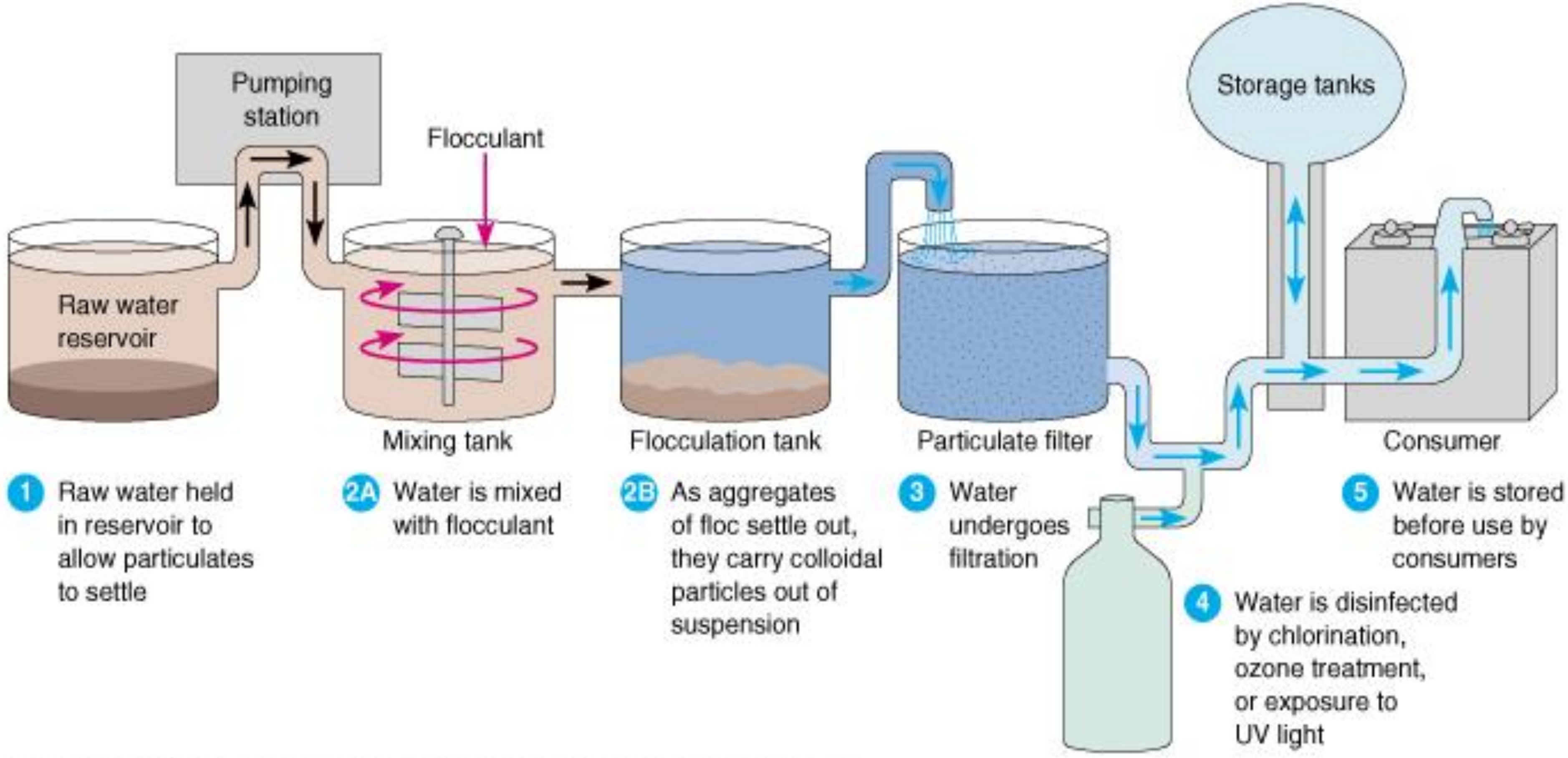
- How do public water facilities treat our water to make it safe for us to drink and appropriate for other human uses?

There are steps in the treatment of water:

- Screening,
- Straining,
- Sedimentation,
- Coagulation & flocculation,
- Filtration and disinfection

- Some of these steps, involve chemical and biological
- Other basis of physical characteristics
- Many of these steps depend on one another

Typical layout of a water treatment plant



1 Raw water held in reservoir to allow particulates to settle

2A Water is mixed with flocculant

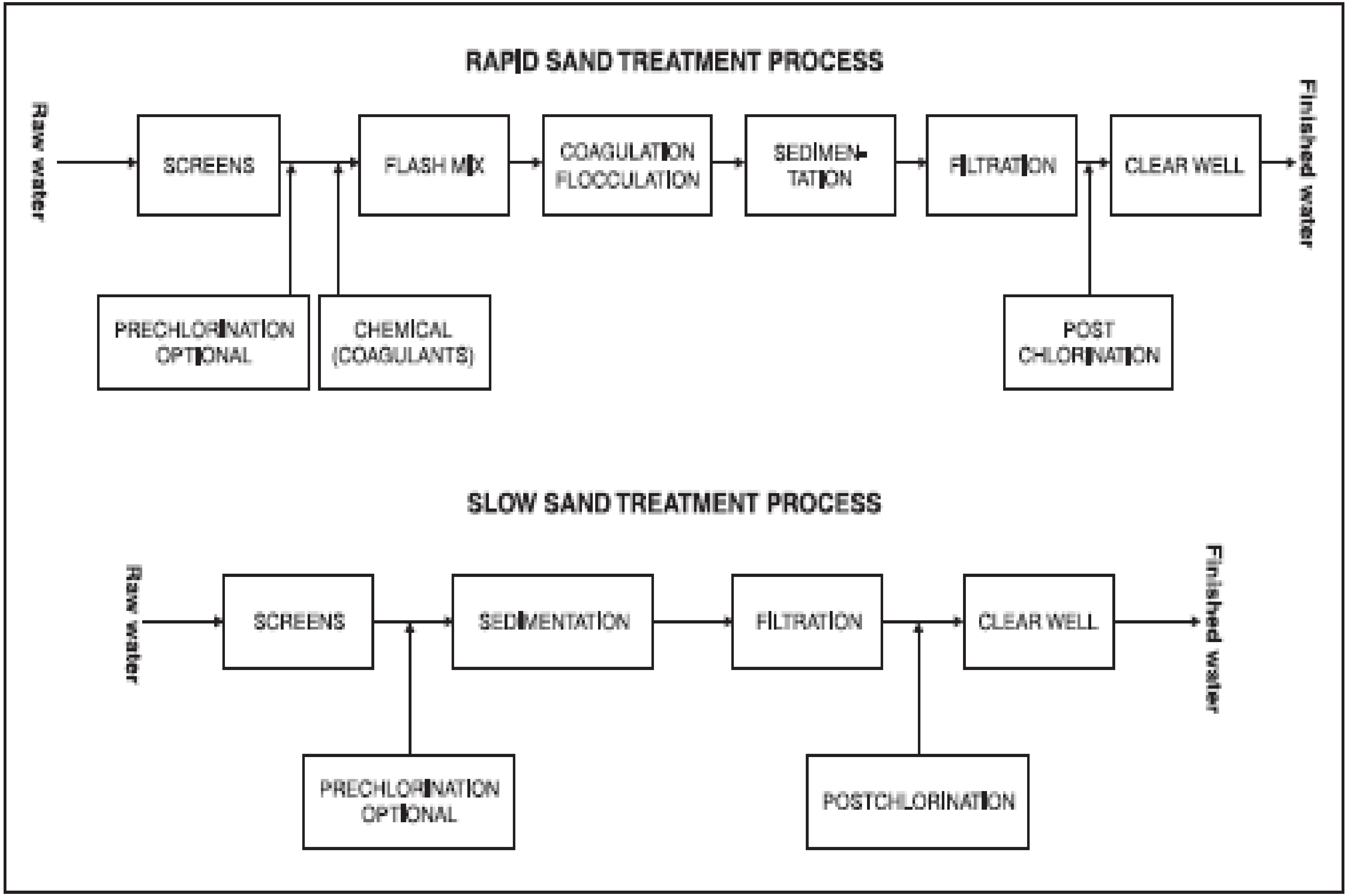
2B As aggregates of floc settle out, they carry colloidal particles out of suspension

3 Water undergoes filtration

4 Water is disinfected by chlorination, ozone treatment, or exposure to UV light

5 Water is stored before use by consumers

- Some of these steps, involve chemical and biological
- Other basis of physical characteristics
- Many of these steps depend on one another



- The difference: Coagulation and flocculation

2.2.1. Preliminary Treatment processes

- Raw water may contain large floating and suspended solids like **leaves, branches and silt particles**.

- To protect the main units
- To aid in their efficient operation
  - Otherwise they could obstruct the flow or damage the equipments

This may involves : **Screening and straining**

Screening

- *Screening* is the removal of any coarse floating objects, weeds, fish etc. from the water that entering water treatment facilities.

- The unit involved is called a *screen.*

- Protects pumps and pipes in WTP

Classification of Screens

- Opening size [Coarse, Medium and Fine]
- Configuration [Bar Screens and Mesh Screens]
- Method used to clean the entrapped materials

  (manually, mechanically, raked or water-jet cleaned)
- Fixed or moving screen surface.

Classifications……………..

- Coarse Bar Racks

– remove coarse debris (twigs, branches, rags, etc)

- Spacing : Coarse 2 – 6 in

Medium 0.8 – 2in

Fine Screens

- 3/8 to ½ in. (up to 10 mm or less,

- book < 6 mm (1/4 in.))

Design Criteria of a Bar Screen

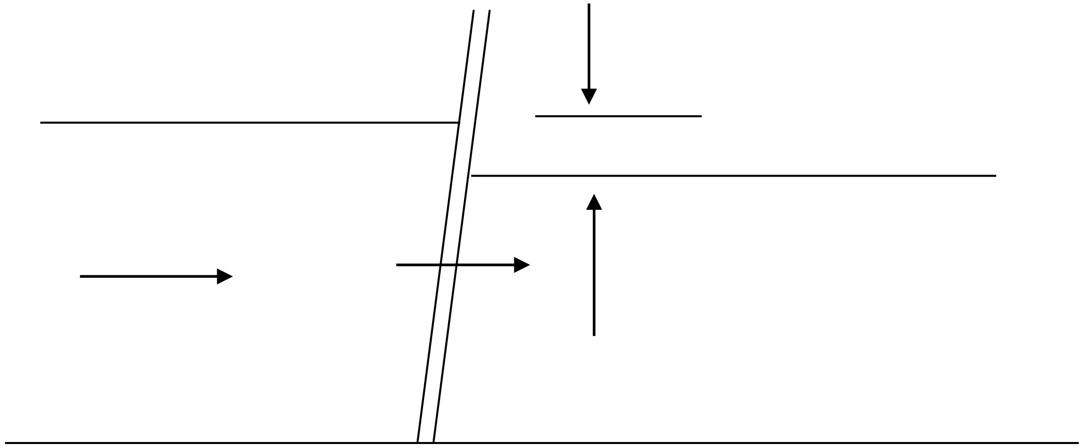
Approach Velocity

- Optimum Velocity : 0.6 m/s (through the screen opening)
- Maximum Velocity : 0.75 - 1.0 m/s to **prevent entrapped materials being forced through the bars**.
- Minimum Velocity : 0.4 m/s to **prevent deposition of solids.**
- Typical Range : 0.6 - 1.0 m/s

Headloss :

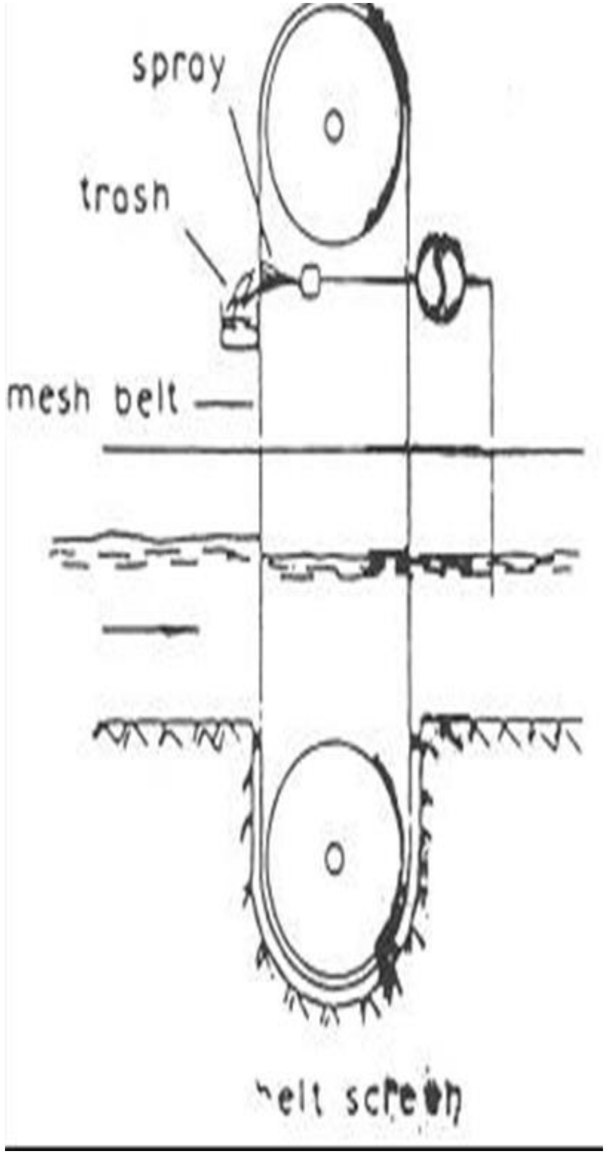
  - hL = 0.05 - 0.15 m **for drinking water**
  - hL = 0.10 - 0.40 m **for sewage** (wastewater)

- Cleaning Mechanism: Manual or Mechanical
- Angle of Inclination (10-60)



Band or Belt Screens

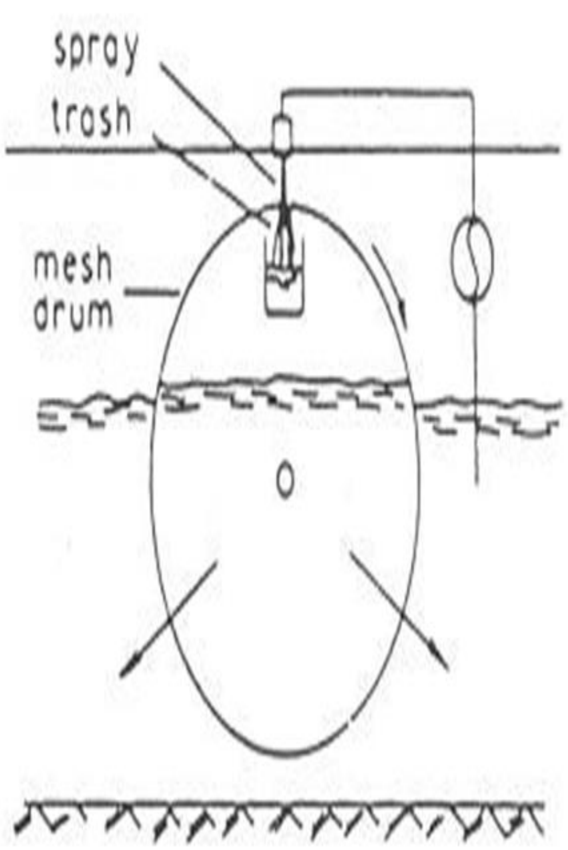
- Flexible woven wire mesh screens normally installed for a river supply.
  - Consists of sections of perforated mild steel plates connected together in a form of a band which is revolved by an electric motor.
  - Water passes inward through the screens and solid matter is washed off by high pressure water jets directed from inside of the screen.



Disk Screens and Drum Screens

Similar in principle to band screens, differing only in the form of the moving screen.

- Rotating metallic disc - partially immersed.
- Solid caught in the screen are taken to the top, where they are scrapped by the moving screen.
- Diameter : 2 to 5 m
- Speed 0.05 m/s
- Hollow drum.
- One end of the drum is closed.
- Water enters through the other end and passes out through the perforation.
- Water jet is used for cleaning



drum screen

Microstraining (Fine Filter)

- Microstrainer have been used to remove suspended solids from raw water containing high concentrations of algae.

- is a development of the drum screen which uses a **fine woven stainless - steel mesh** with aperture sizes of **20 - 60 µm**
- Clogging occurs rapidly
    - drum is rotated at a peripheral speed of about **0.5 m/s** and
    - the mesh continually washed clean by **high-pressure sprays**

2.2.2. Aeration

- Aeration is the treatment process whereby water is brought into intimate contact with air.

Purpose:

- Increasing the oxygen content,
- Reducing the carbon dioxide content, and
- Removing hydrogen sulphide, methane and various volatile organic compounds responsible for bad taste and odor.
- Removing of dissolved minerals (iron and manganese)

- widely used for the treatment of groundwater having **too high iron and manganese**
  - These substances impart
    - a bitter taste to the water
    - discolor rice cooked in it and
    - give brownish-black stains to clothes washed and
    - white enamel buckets, bowls, sinks, baths and toilets
- For the treatment of surface water, when the water has a **high content of organic matter**.

For drinking water treatment it is mostly achieved by:-

1. Dispersing the water through the air in thin sheets or fine droplets (*waterfall aerators*), or

2. By mixing the water with dispersed air (*bubble aerators*).

In both ways the oxygen content of the water can be raised to **60-80%** of the maximum oxygen content that the water could contain when fully saturated.

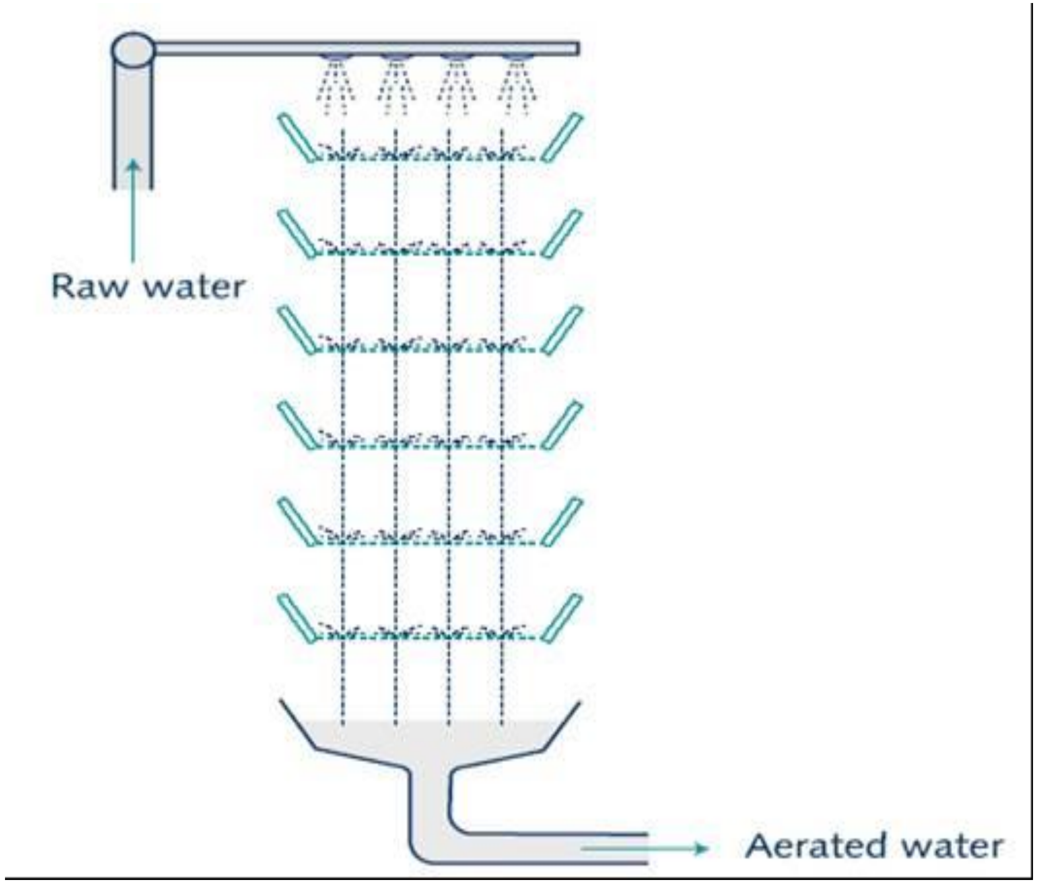
I. Waterfall aerators

- In waterfall aerators there is an appreciable release of gasses from the water;

- The reduction of carbon dioxide by waterfall aerators can be considerable, but is **not always sufficient** when treating very corrosive water.
  - A chemical treatment such **as lime dosing** or filtration over marble or burned dolomite would be required for this type of water.

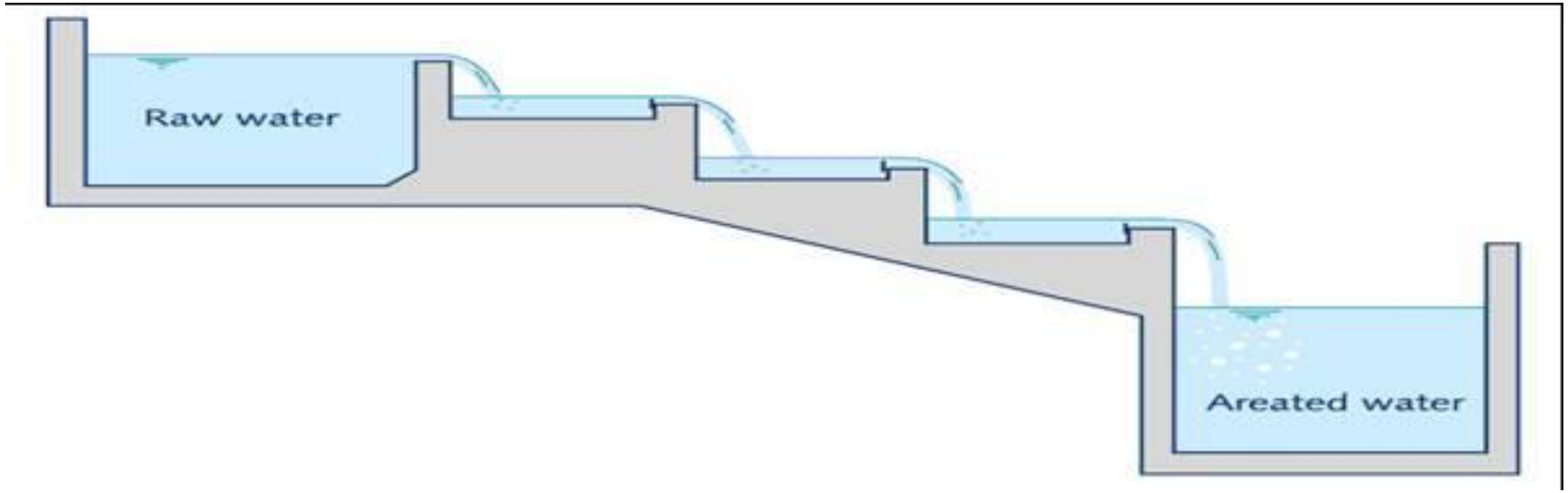
Types of waterfall aerators

A. Multiple tray aerator - provides a very simple and inexpensive arrangement and it occupies little space.



- ferrocement or plastic plates with holes
- 4-8 trays
- perforated bottoms
- intervals of 30-50 cm
- trays can be filled with coarse gravel about 10 cm deep For finer dispersion

B. Cascade aerator



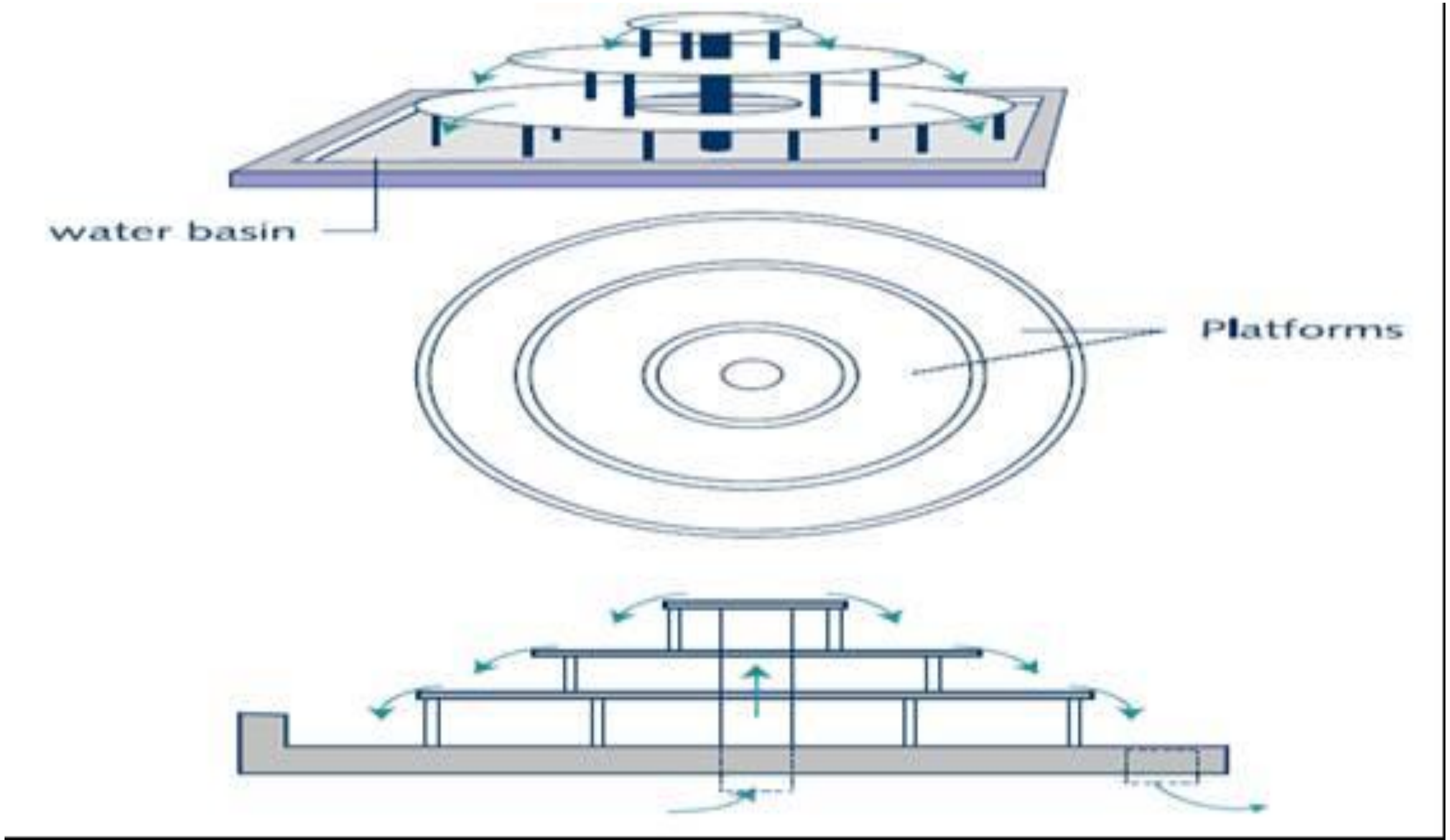
- 4-6 steps, each about 30 cm high with a capacity of about 0.01 m^3/s per meter of width

- Obstacles are often set at the edge of each step

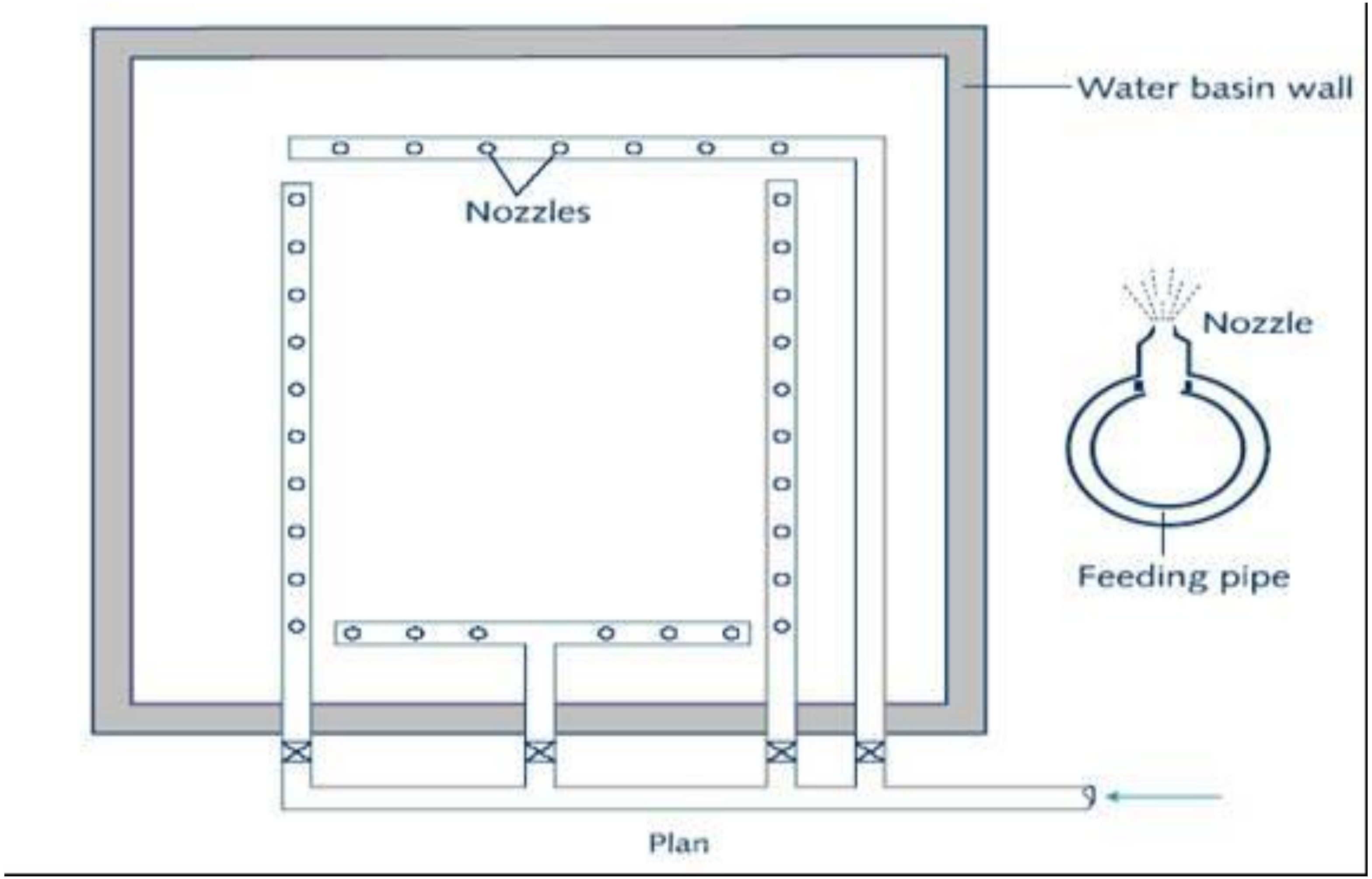
- the space requirements of cascade aerators are some-what larger

C. Multiple platform aerator

- uses the same principles



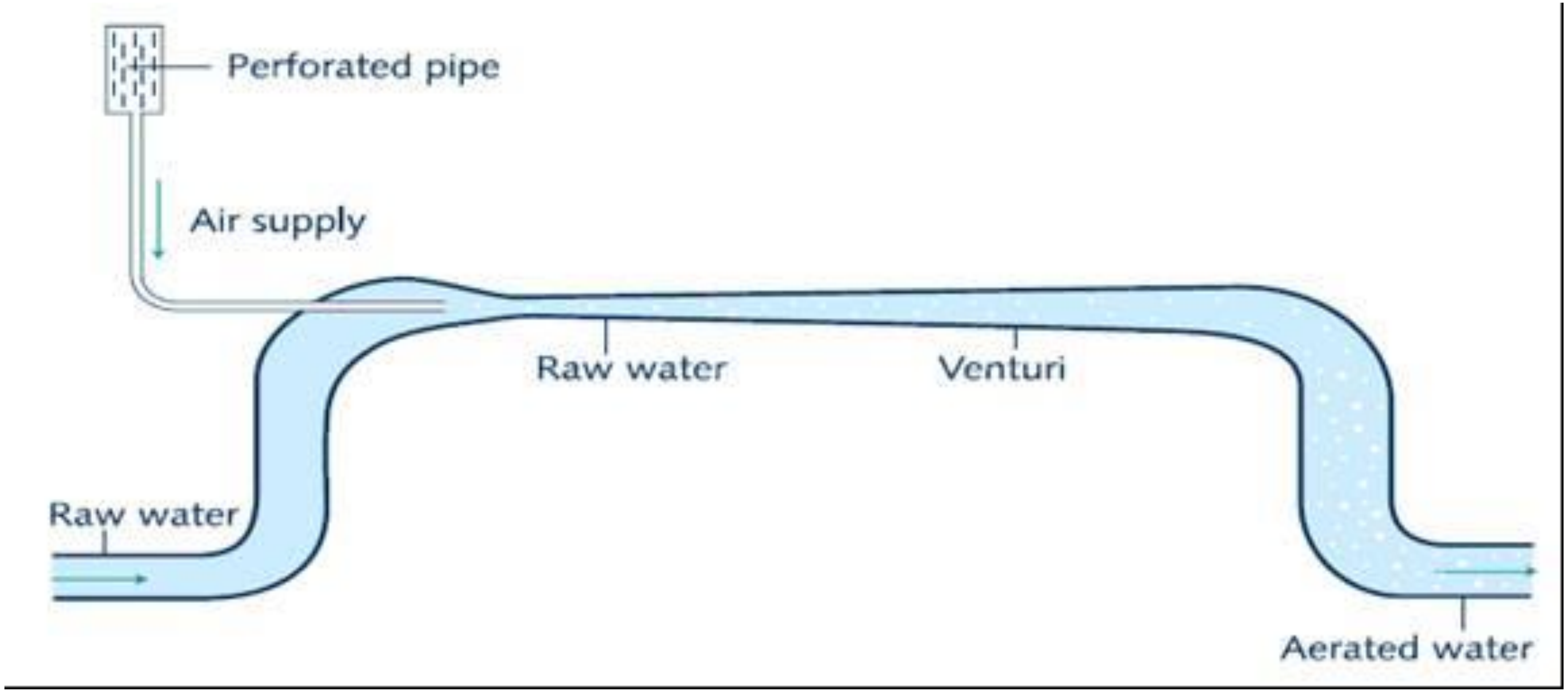
D. Spray aerators



- water is sprayed into the surrounding air at velocities of 5-7 m/s.

II. Bubble aerators

- The amount of air required for bubble aeration of water is **small**, no more than 0.3-0.5 m^3 of air per m^3 of water, and these volumes can easily be obtained by a sucking in of air.
- Ex. **venturi aerator**



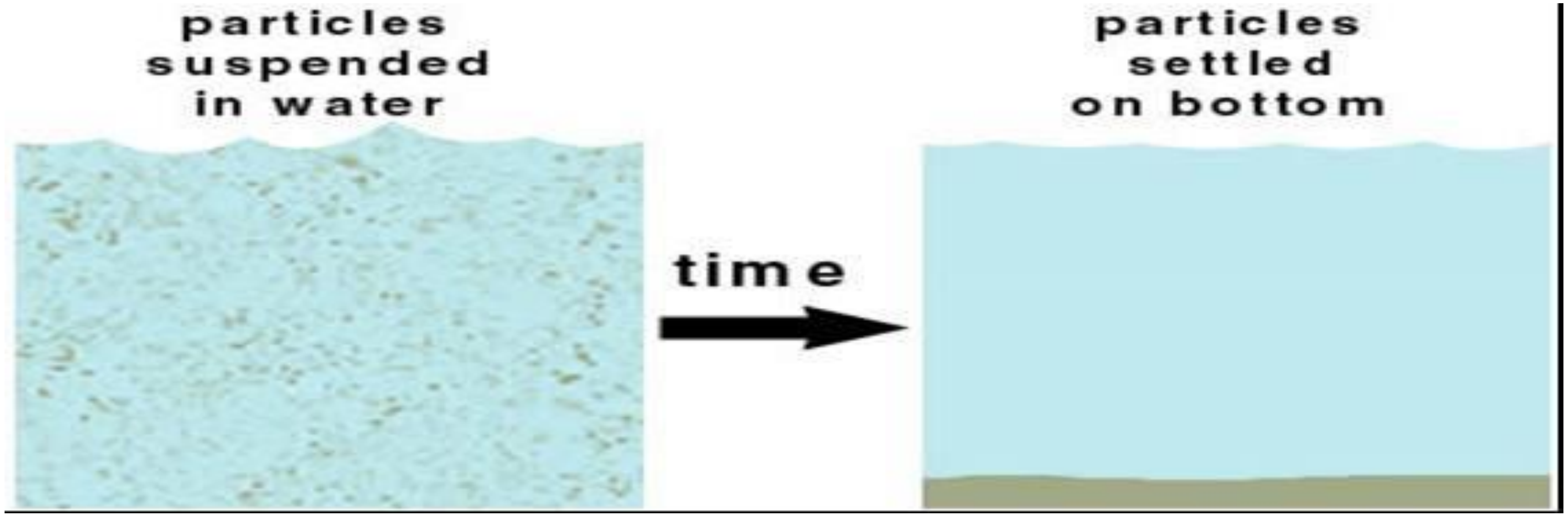
2.2.3. Sedimentation

- What impurities remain in raw water at this step?
  - suspended matters such as
    - reduced iron and manganese,
    - bacteria and
    - organic colloids

- Actually sedimentation start in the reservoir

- **plain sedimentation**: Sedimentation without pre-treatment

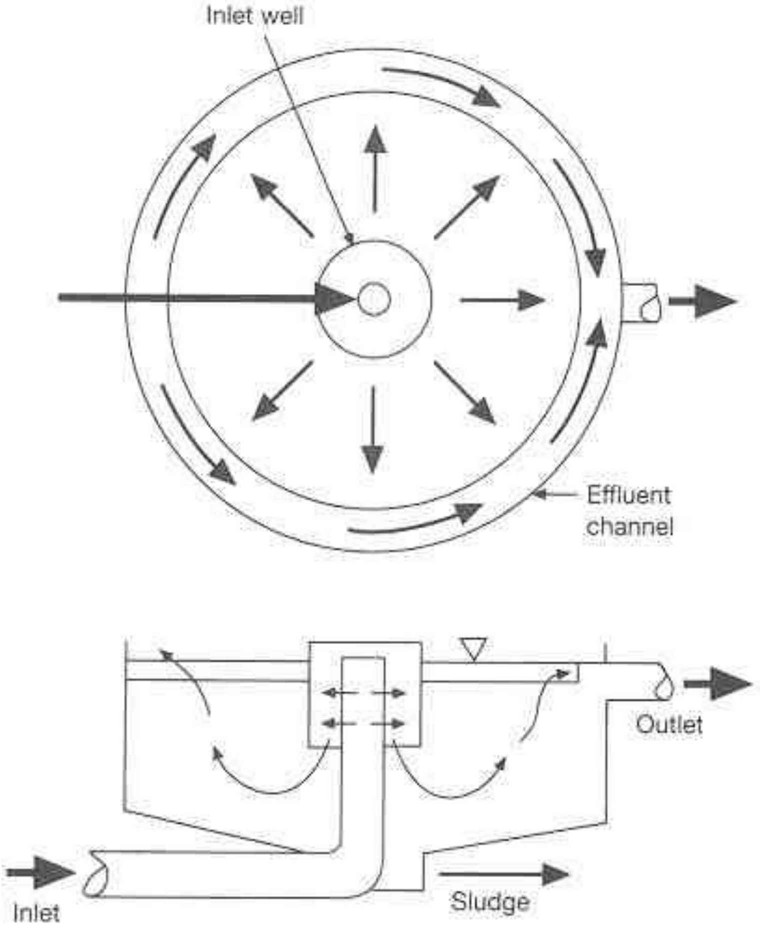
- pretreatment like aeration, coagulation and flocculation are required before **sedimentation**



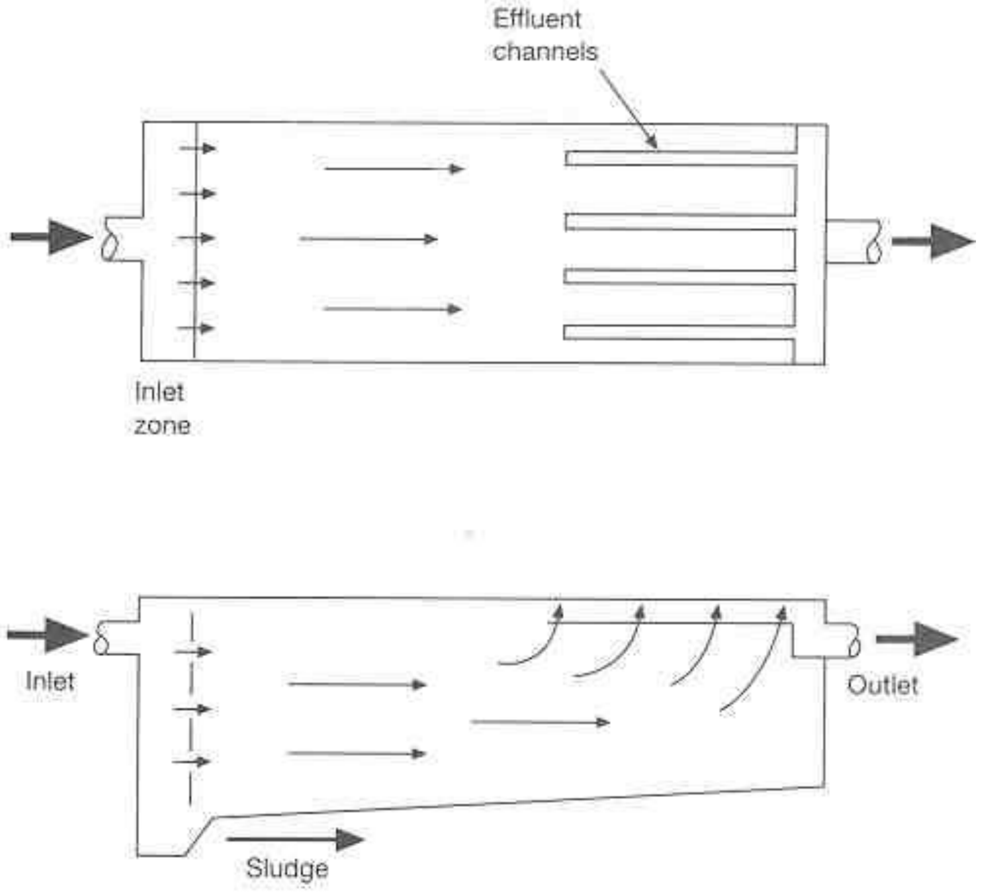
- Mass density (specific weight) of particles
- The efficiency of settling process: turbulence or cross-circulation
  - Separate inlet structure
  - Water must be divided evenly
  - Outlet structure is required

- Need to be cleaned out regularly

Circular Basin



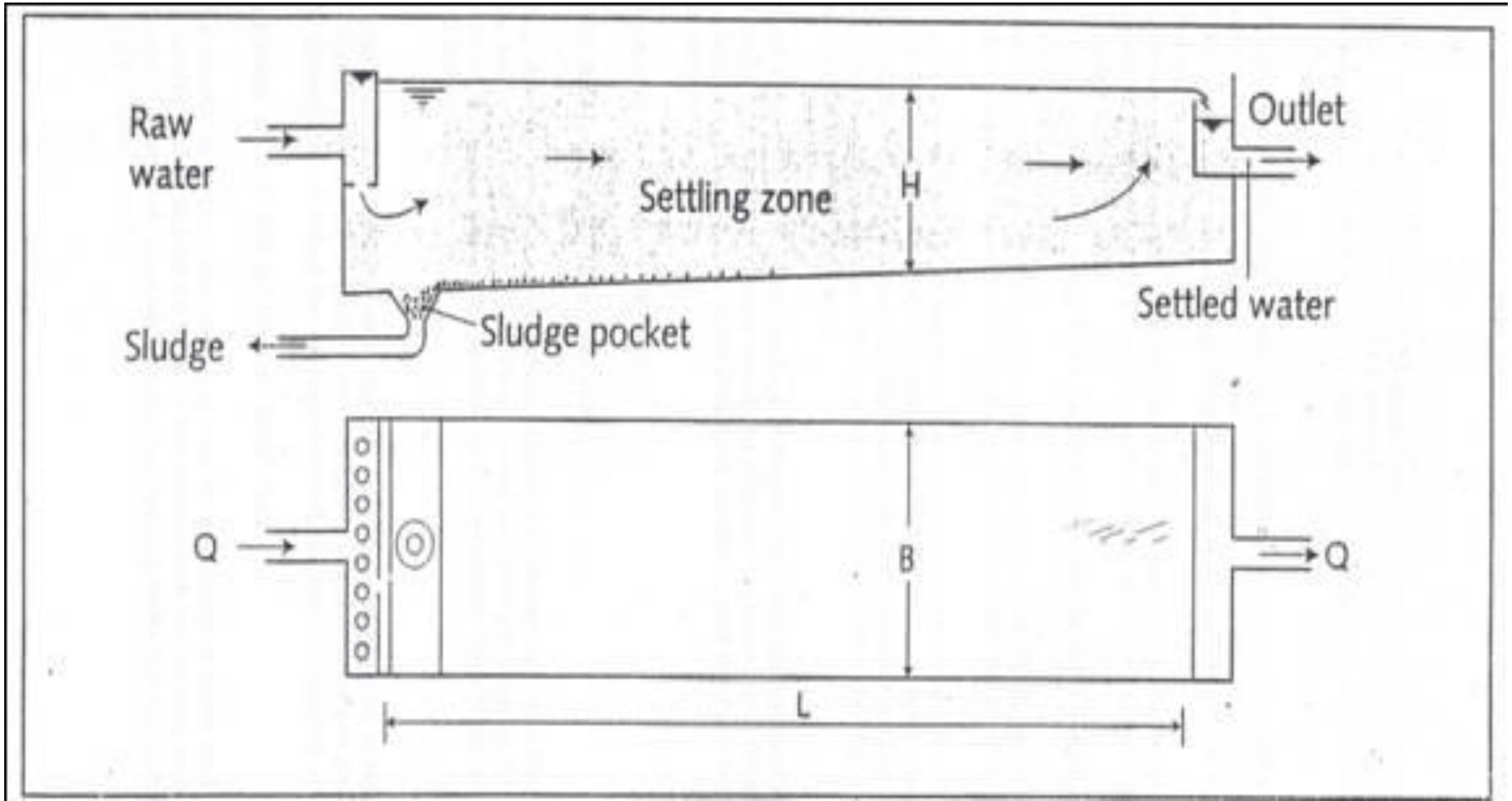
Rectangular Basin



Settling tank design

The efficiency of settling tank can be determined by:

- the **settling velocity (s)** of a particle that in the **detention time (T)** will just cross the full **depth (H)** of the tank



$S_0 = H \div T$

$T = BLH \div Q$

So that: $S_0 = Q \div BL$ ($m^3/m^2 \cdot h = m/h$)

Where:

S0= setting velocity (m/h)   T = detention time (h)

Q= flow rate (m^3/h)   H = depth of tank (m)

B= width of tank (M)   L = length (m)

Settling time for particles of various diameters

Diameter of Particle	Type of Particle	Settling time through 1 m. of water
10mm	Gravel	1 seconds
1mm	Sand	10 seconds
0.1mm	Fine Sand	2 minutes
10 micron	Protozoa, Algae, Clay	2 hours
1 micron	Bacteria, Algae	8 days
0.1 micron	Viruses, Colloids	2 years
10 nm	Viruses, Colloids	20 years
1 nm	Viruses, Colloids	200 years

Remark:

- Assuming an even distribution of all suspended particles in the water over the full depth of the tank (by way of an ideal inlet structure).

- Particles having a setting velocity (S) higher than S_0 will be completely removed.
- particles that settle slower than “S” will be removed for a proportional part **S: S_0**

- Settling efficiency basically only depends on the ratio between the **influent flow rate** and the **surface area of the tank**
  - This is called the **Surface loading**
    - Independent of the depth
      - In principle, there is no difference in setting efficiency between a **shallow and a deep** tank.

- The design of settling tank should properly be based on an analysis of the **setting velocities of the settleable particles** in the raw water.

- For plain Sedimentation: the surface loading should be in the range from **0.1-1 m/hour**

- Sedimentation with pretreatment: somewhere between l and 3 m/hour

- In general: lower the surface loading the better the clarification of the water

- The above considerations ignore the effects of turbulence, short-circuiting and bottom scour caused by inlet and outlet design and winds.

- Inlet and outlet structure

- Windbreaks of **about 2 m high** can reduce wind disturbance

- the tank should **not be too shallow**, at least 2m deep or more

- the ratio between length and width should be between **3 and 8.**

Example 1

Assume that you are assigned to design sedimentation tank for the water treatment plant of a community that consume 40 m^3 water per hour. Initially you proposed that the depth of tank is 3 meter and the detention time is 2 hour

What should be:-

A. the surface loading of the tank

B. the surface area of the tank

C. average sludge accumulation in the tank per month (assuming the raw water contains a suspended load of 150 mg/l which is to be reduced to 10 mg/l by sedimentation processes)

D. Sludge capacity

Example 2

A water treatment plant has a flow rate of 0.6 m^3/sec. The settling basin at the plant has an effective settling volume that is 20 m long, 3 m tall and 6 m wide. Will particles that have a settling velocity of 0.004 m/sec be completely removed? If not, what percent of the particles will be removed?

$$S_0 = Q/A = 0.6 \text{ m/sec} \;/\; (20 \text{ m} \times 6 \text{ m}) = 0.005 \text{ m/sec}$$

Since S_0 is greater than the settling velocity of the particle of interest, they will <u>not</u> be completely removed.

The percent of particles which will be removed may be found using the following formula:

$$\text{Percent removed} = (S/ S_0)\,100 \quad = (0.004/0.005)\,100 = 80\ \%$$

Example 3

How big would the basin need to be to remove 100% of the particles that have a settling velocity of 0.004 m/sec?

$$S_0 = Q / A$$

$$0.004 = 0.6 / A$$

$$A = 150 \text{ m}^2$$

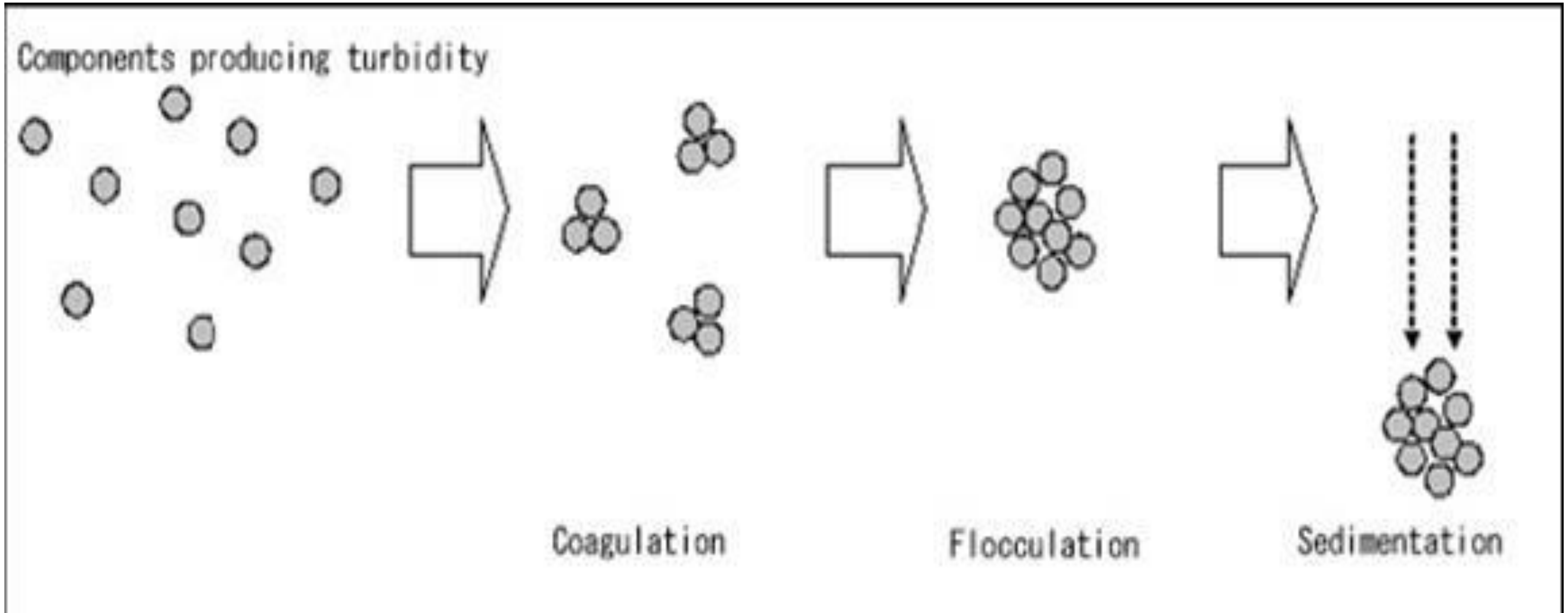
If the basin keeps the same width (6 m):

$$A = 150 \text{ m}^3 = 6\text{m} \times L$$

$$L = 25 \text{ m}$$

2.2.4. Coagulation and flocculation

- Some particles are **too small to settle out** quickly enough to use sedimentation alone
- Involves adding chemicals to the water
  - chemicals are called **coagulants**, and have a positive charge



- There are two general type of coagulant:

I. Primary coagulants
II. Natural coagulants

I. Primary coagulants

- Metal coagulants based on **aluminum and iron**
- The choice of coagulant should be determined under laboratory conditions (e.g., **jar testing**)
  - final choice influenced by **economic considerations**

Alum salts

- Alum (aluminum sulfate; $A1_2\ (SO_4)_3.nH_20$) where n=14, 16, or 18, depends on the form of alum supplied
- This may be in liquid solution, broken crystalline granules 2-5 cm size or crystalline blocks
- It is by far the most widely used coagulant
- Alum is a relatively **inexpensive coagulant** if local production is possible.

Ferric Salts

Four types of ferric salts are used as coagulants:

- –Ferric chloride($FeC1_3$)
- –Ferric sulfate($Fe_2(SO_4)_3.9H_2O$),
- –Ferrous sulfate (copperas), and
- –Chlorinated copperas

- In general, they give similar results when their doses are compared in terms of iron content.

How the processes work?

- Colloids are stabilized by negative electric charges on their surfaces

- $Al_2 (SO_4)_3 + 6H_2O \rightarrow 2Al (OH)_3 \downarrow + 3H_2SO_4$
  - a gelatinous precipitate (it adsorbs the impurities)
  - the hydrogen ion destabilize colloids

Practical differences between alum and ferric coagulants:

- Iron salts over aluminum is the **broader pH range** for good coagulation

- The floc formed with ferric coagulants is **heavier** than alum floc

- The ferric hydroxide floc does **not re-dissolve at high pH** values.

- Optimal floc formation using alum occurs when the pH value of the water is between **6.0 and 8.0**

    - If insufficient alkalinity is present to react with the alum, an alkali such as **lime must be added**

Dosage

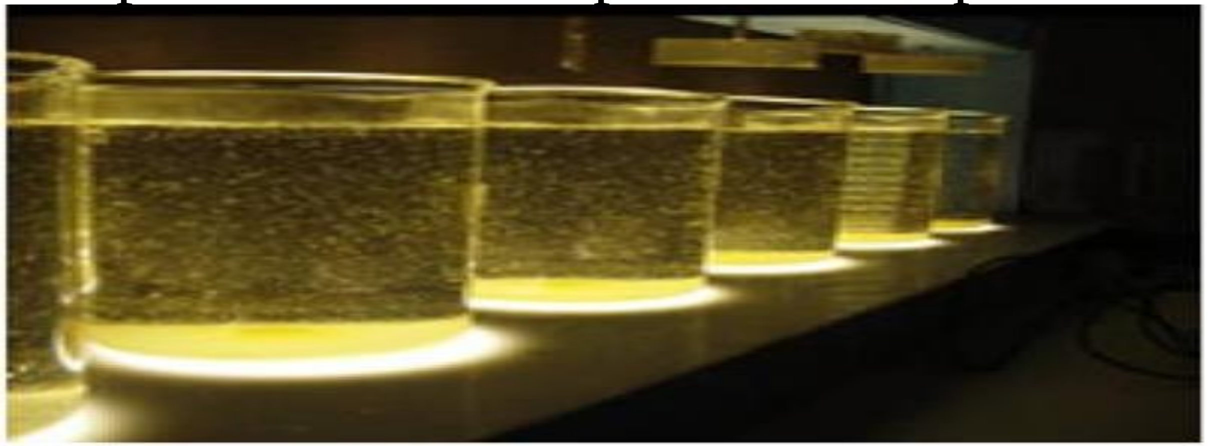
For good coagulation

  - optimal dose of coagulant should be fed
  - quickly and properly mixing

- optimal dose will vary depending
  - the nature of the raw water and
  - its overall composition
- not possible to compute the optimal coagulant dose for particular raw water
  - laboratory experiment called the **jar test** is generally used for the **periodic determination** of the optimal dose.

Jar test

- A series samples of water are placed on a special multiple stirrer



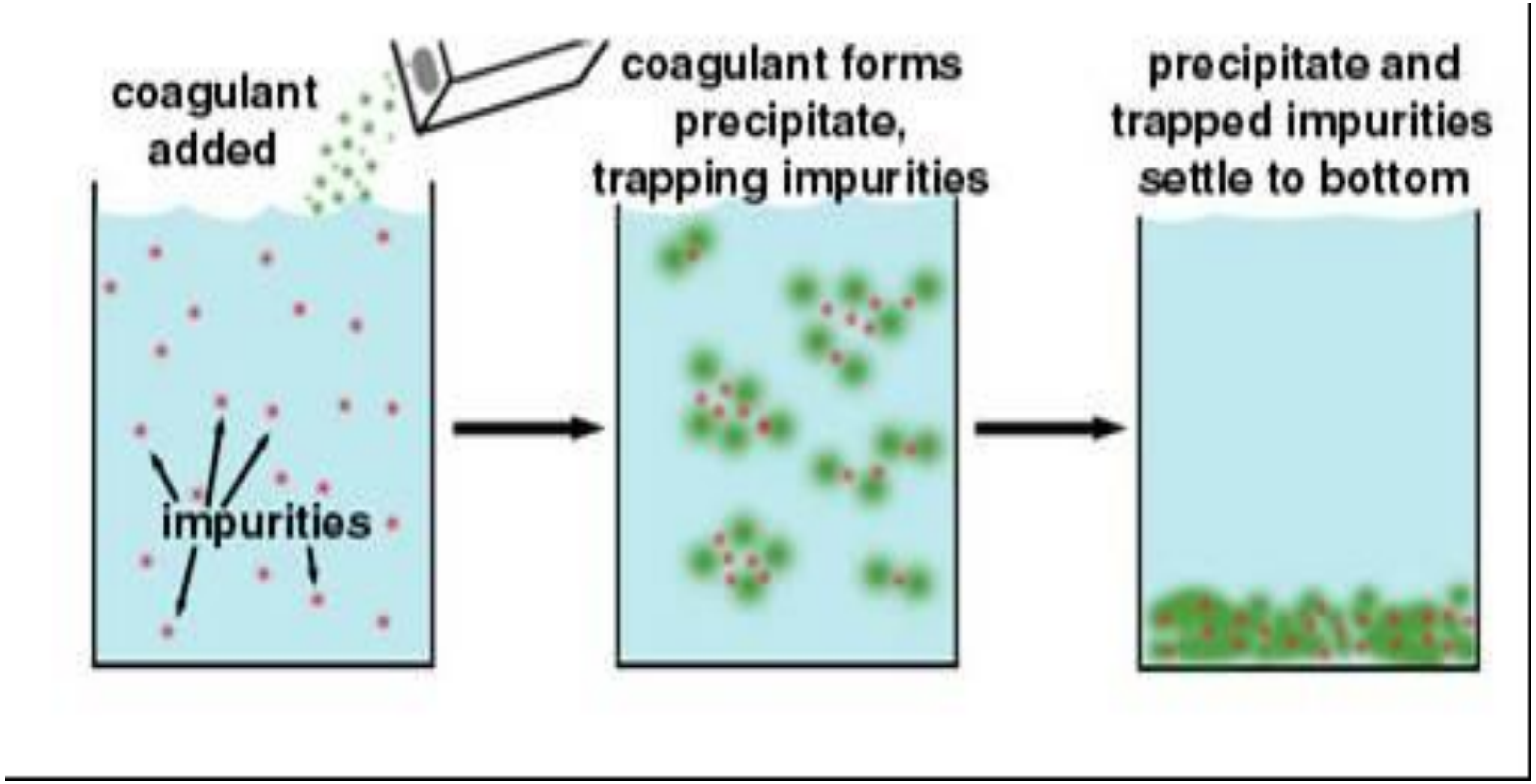
- the samples, typically 800 ml in 1-litre beakers (or jars), are dosed with a range of coagulant, **e.g.10, 20,30,40 and 50 mg/1**, and are **stirred vigorously for about one minute**
- **gentle stirring** (10 minutes),
- allowed to stand and settle for **30-60 minute**.
- **examined for colour and turbidity**
- coagulant that gives satisfactory clarification of the water is noted.

The dosage of coagulants may be reduced in some instances by:

- Pre treating excessively turbid river waters,
- Direct filtration of low turbidity (,50 NTU) waters,
- The use of coagulant aids, and
- Optimum pH adjustment.

Coagulation comprises:

1. Addition of coagulant
2. Rapid Mixing
3. Flocculation (Formation and growth of Flocs)
4. Removal of Flocs.

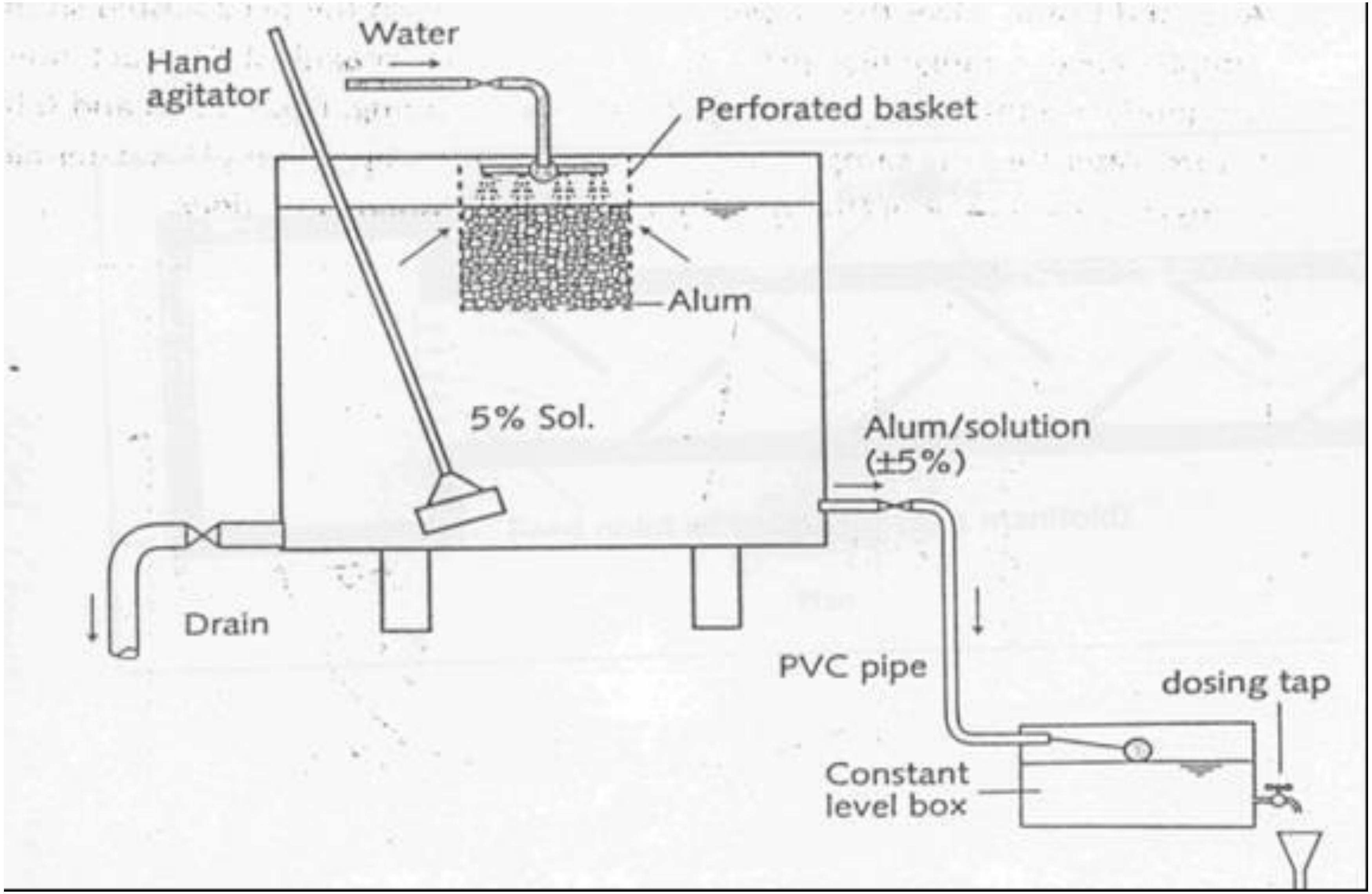


1. Addition of coagulant (Dosing methods)

- The most common method is in the **form of a solution**
    - Such a solution usually of **3-7% strength**

    - **Two tanks** are required, one in operation, while the solution is being prepared

    - When using alum in solutions of **less than 1%** strength, the chemical is hydrolyzed in chemical feed water
        - To prevent this, the solution should always have strength of **more than 1.5%.**



Ex. chemical feed arrangements

2. Rapid mixing

- aims at **the immediate dispersal** of the entire dose of chemicals
- agitate the water violently
- inject the chemical in the most turbulent Zone
  - to ensure its uniform and rapid dispersal
  - hydrolysis of the coagulant is almost instantaneous

- rapid mixer should be near to the “chemical house”

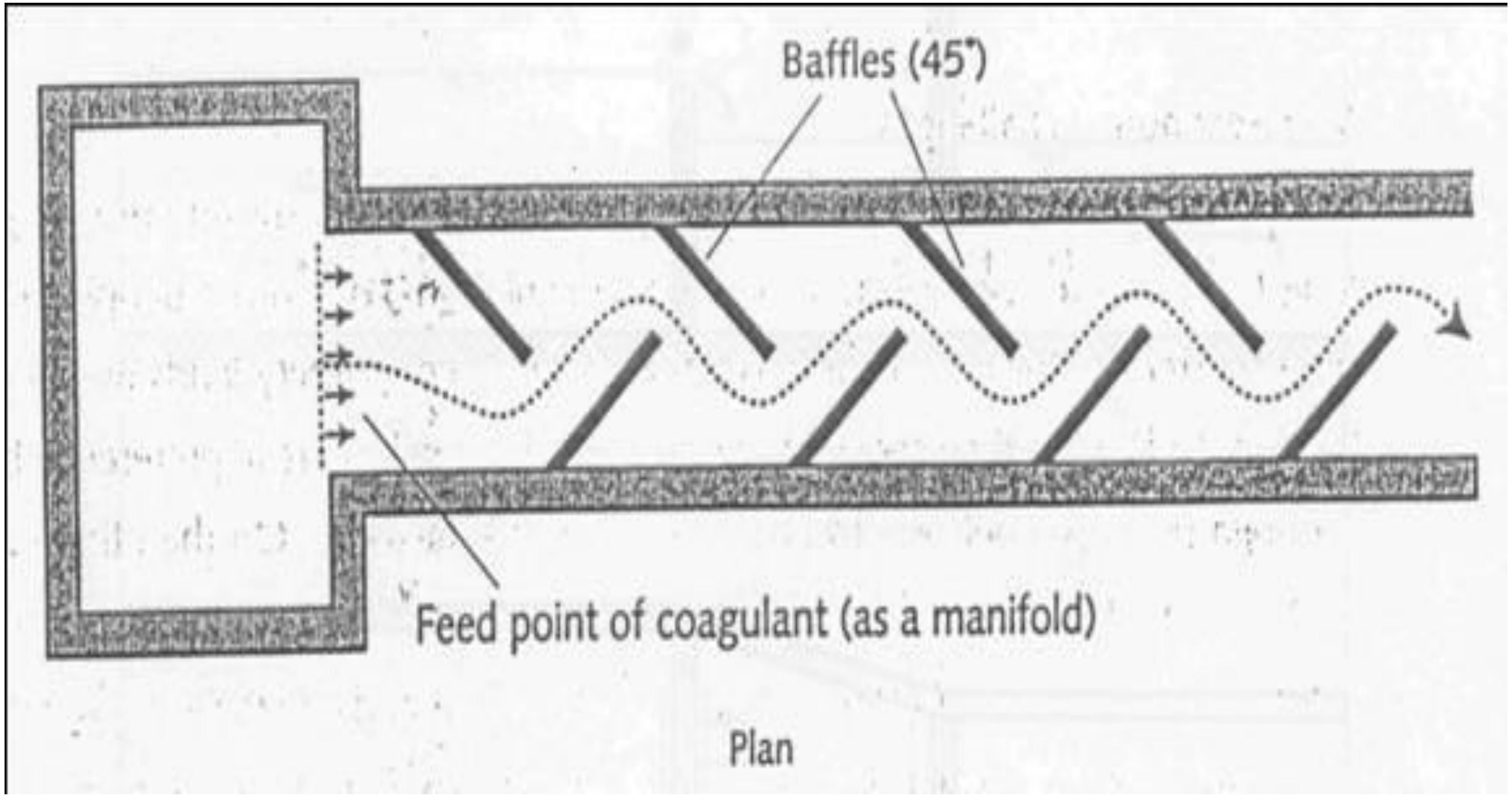
- rapid mixing device close to the flocculators

- Many devices are available for mixing.
  - Basically, there are two groups:
    - » **Hydraulic rapid mixing**
    - » **Mechanical rapid mixing**

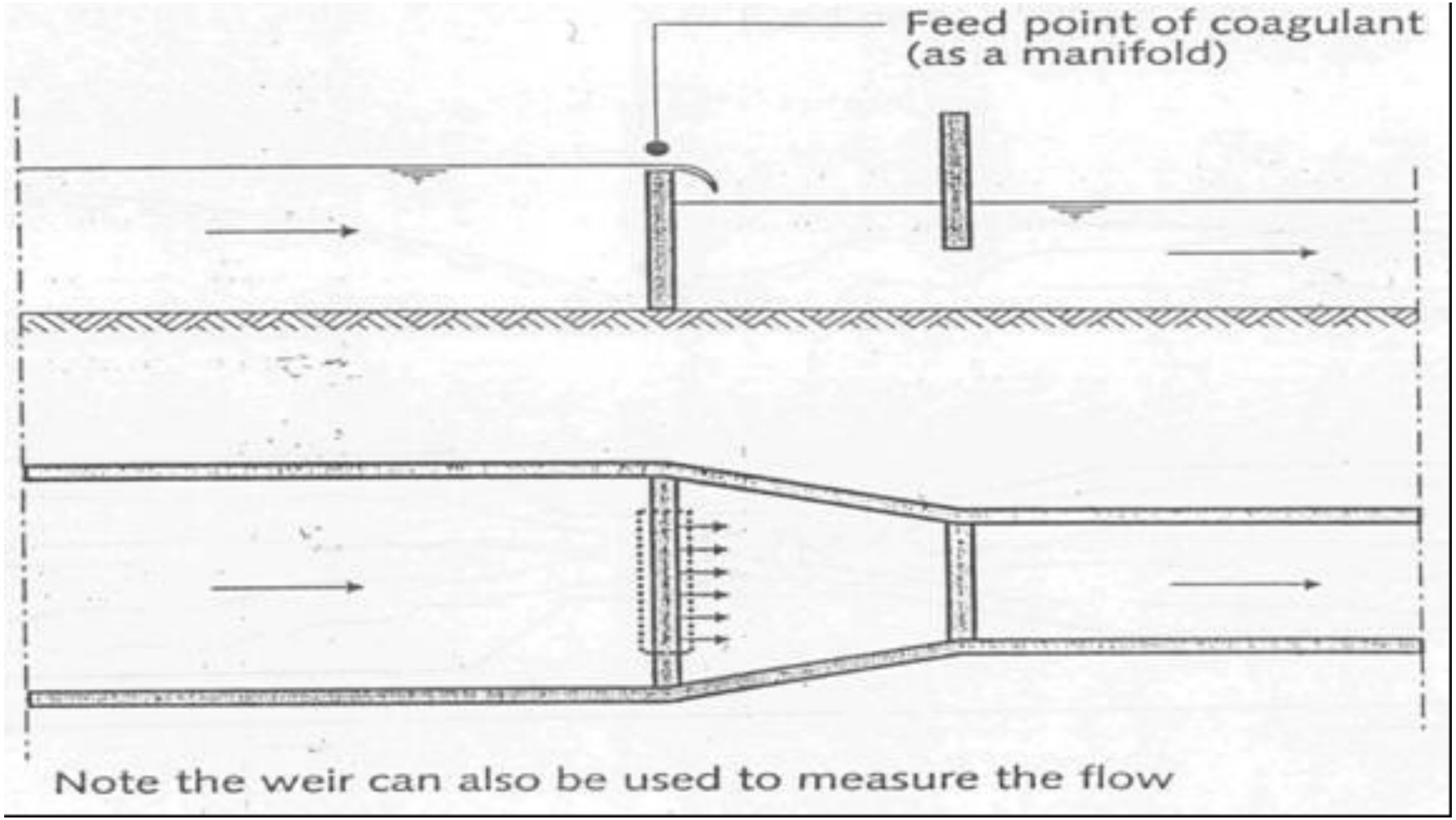
Hydraulic rapid mixing

» arrangements are used such as channels or chambers with baffles , overflow weirs, and hydraulic jumps

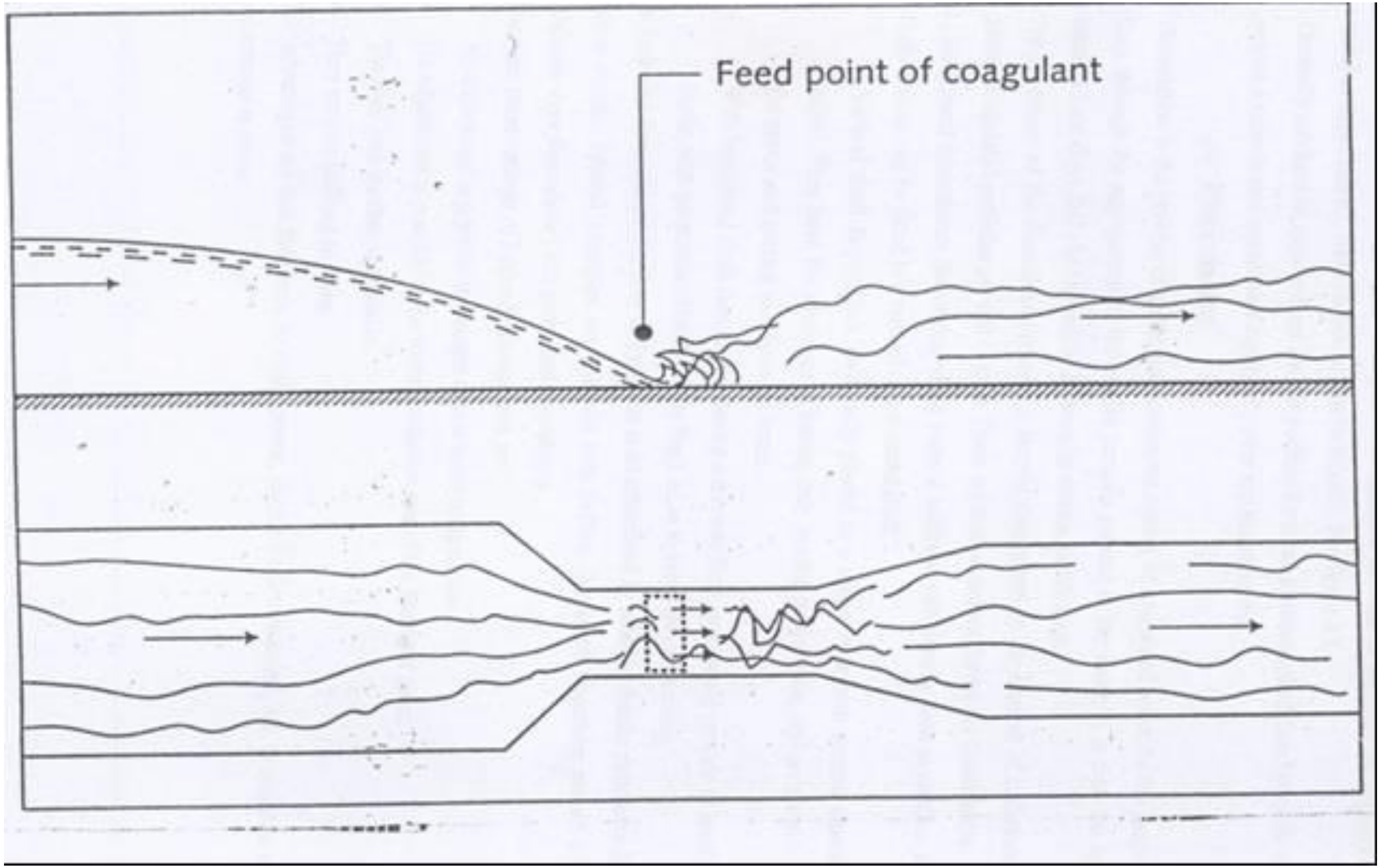
» With a good design, a hydraulic mixer can be as effective as a mechanical mixing device



Baffled channel for rapid mixing



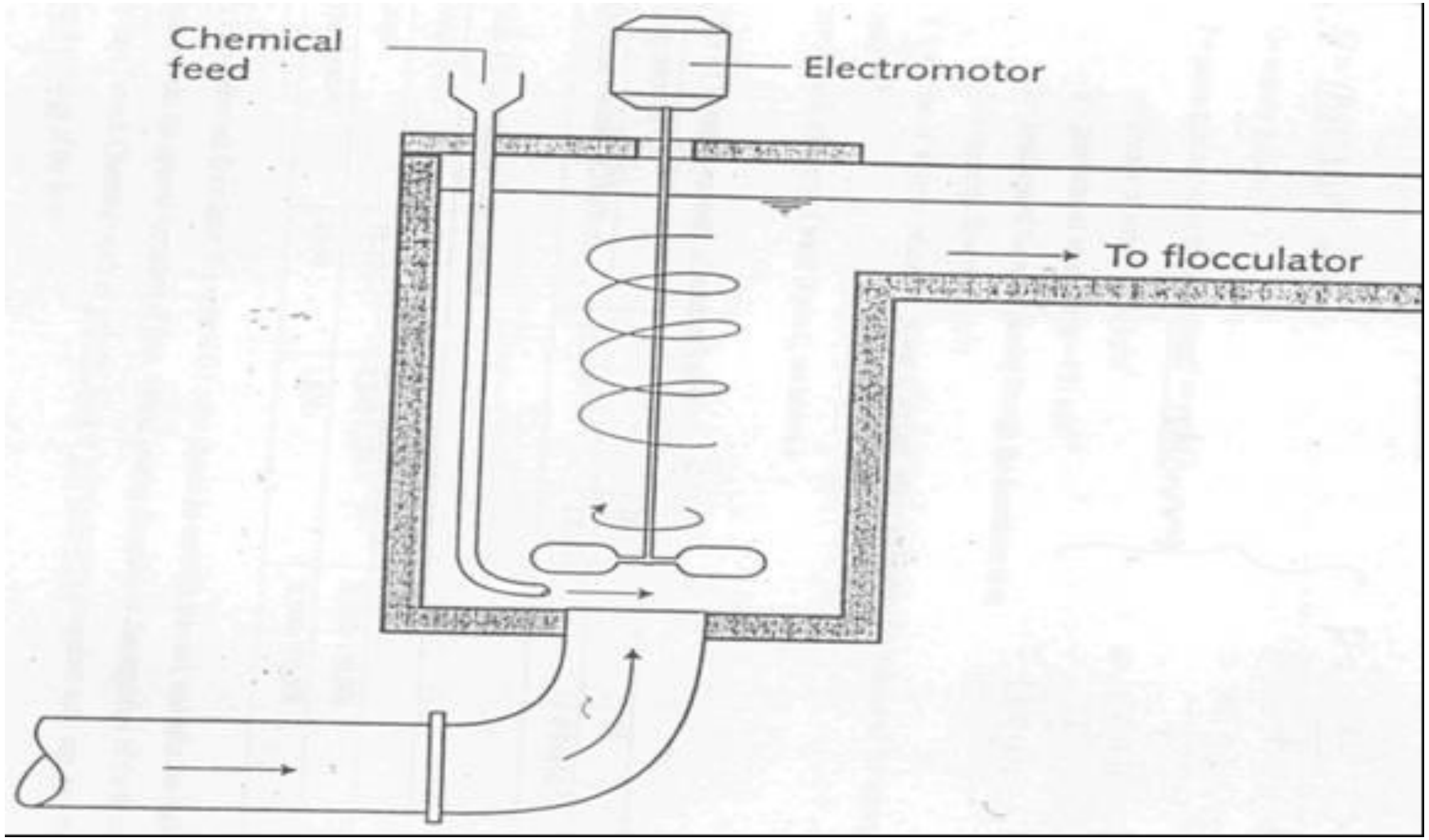
overflow weir



Hydraulic jump

Mechanical rapid mixing

- power required for agitation of water is imparted by impellers, propellers or turbines
- less suitable for small treatment plant



Flocculation (Formation and growth of Flocs)

- process of **gentle and continuous stirring** of coagulated water
- the purpose of **forming flocs** through the aggregation of the **minute particles** present in the water
- Form flocs that can be readily **removed by setting, or filtration**
- The efficiency of the flocculation process is largely determined by **the number of collisions**

- There are **hydraulic** and **mechanical flocculators**.

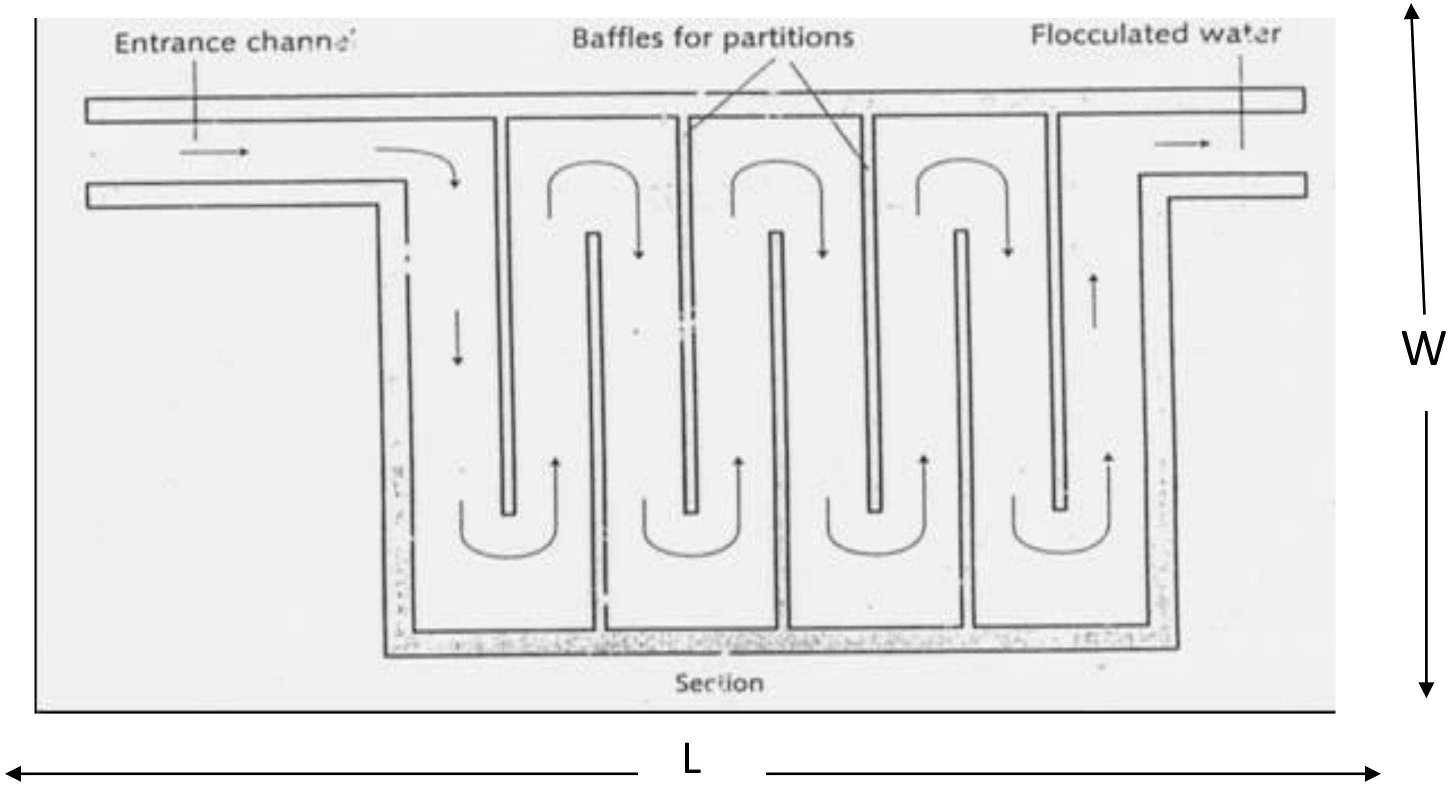
- In **hydraulic flocculators:**
  - by **small hydraulic structures** that a stirring action results

- In **mechanical flocculators:**
  - **achieved with devices** such as paddles, reels or rakes.
  - These devices can be fitted to a **vertical or horizontal shaft.**

Typical examples of Hydraulic flocculators

- Horizontal – flow baffled chamber flocculator

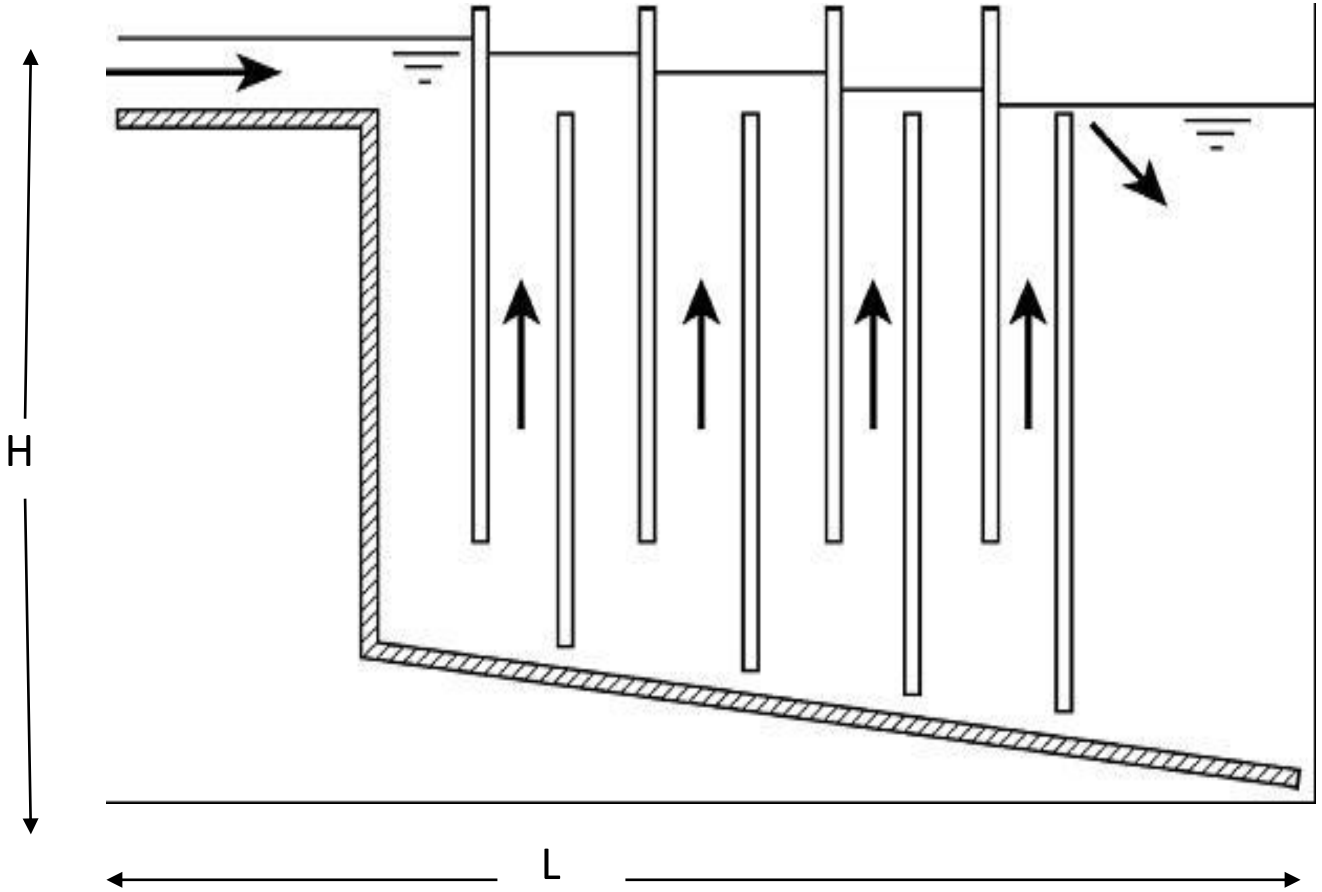
- The water flows horizontally



- velocity usually is in the 0.10-0. 30 m/s range.
- Detention time normally is 15-20 minutes
- suited for very small treatment plants
- efficiency is highly dependent on the depth of water in the baffled channel

vertical - flow baffled chamber flocculator (cross-section)

The water flows vertically



- used for medium and larger- size water treatment plants
- flow velocity range is 0.1-0.2 m/s
- detention time is 10-20 minutes.

Hydraulic flocculators: simple technology

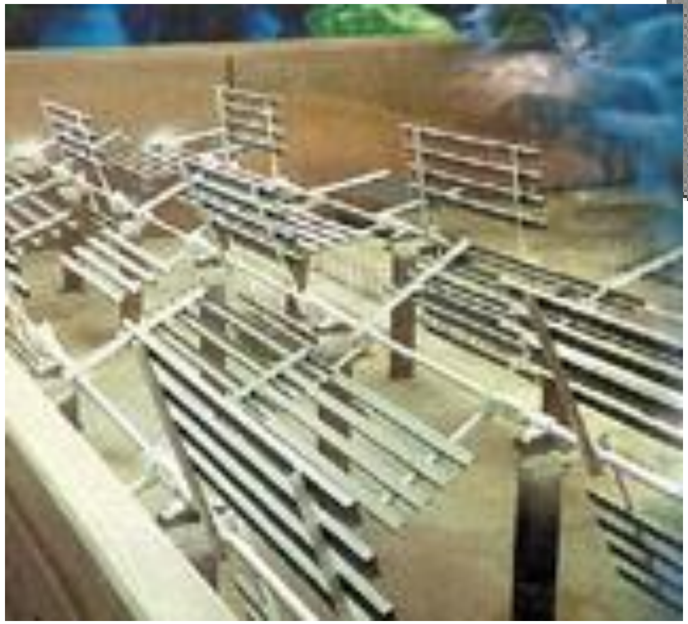
Hydraulic Flocculation: Pipe

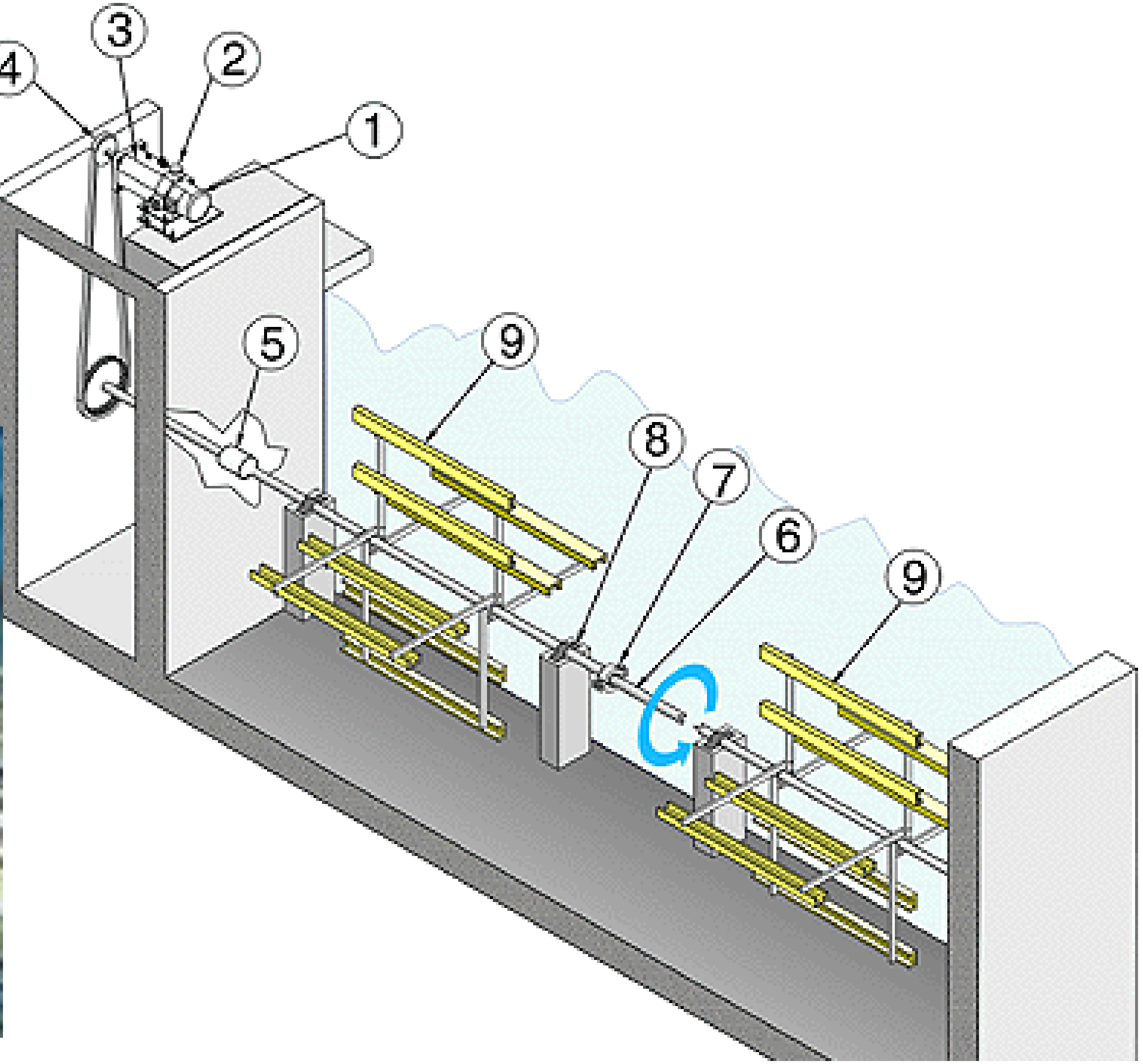
The main **shortcomings of hydraulic flocculators** are:

  - No adjustment is possible to changes of raw water composition.
  - No adjustment is possible to the water production rate of the treatment plant.
  - The head loss is often appreciable.
  - They may be difficult to clean.

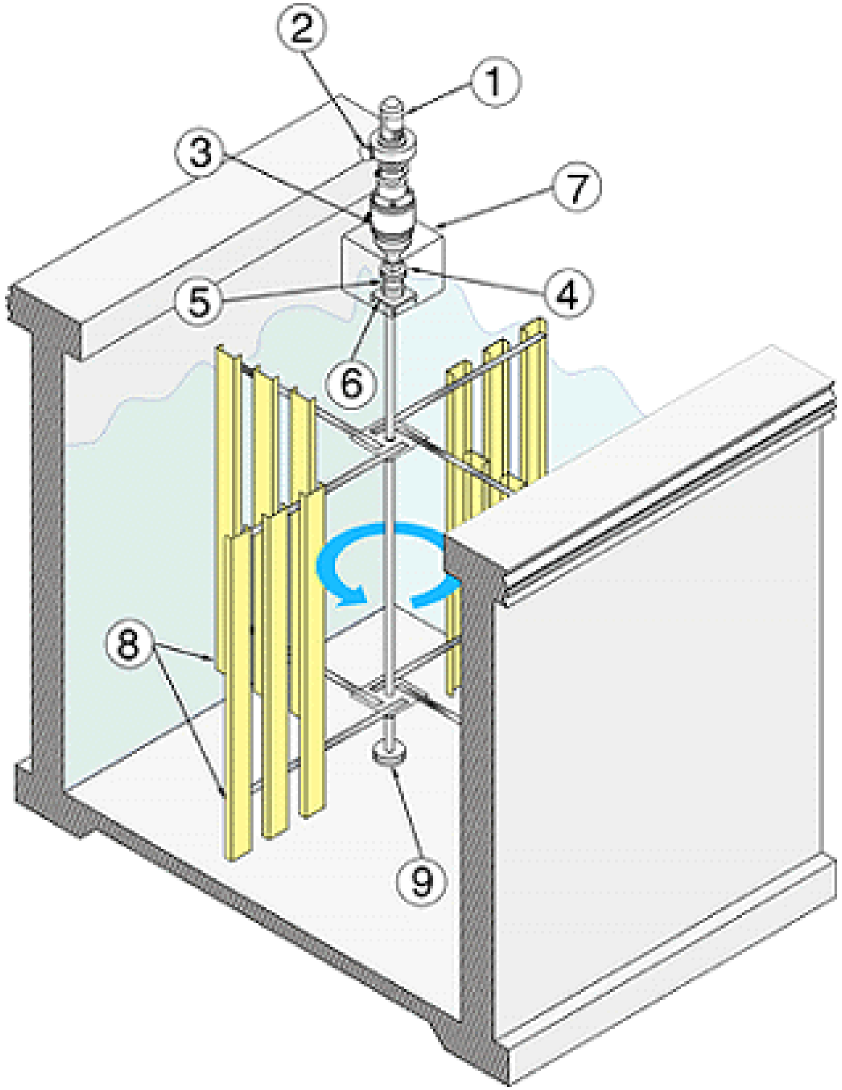
- **Their advantages are**:
  - no motor power
  - electric cable switchgear, etc. to maintain and general maintenance is easier.

Mechanical flocculators

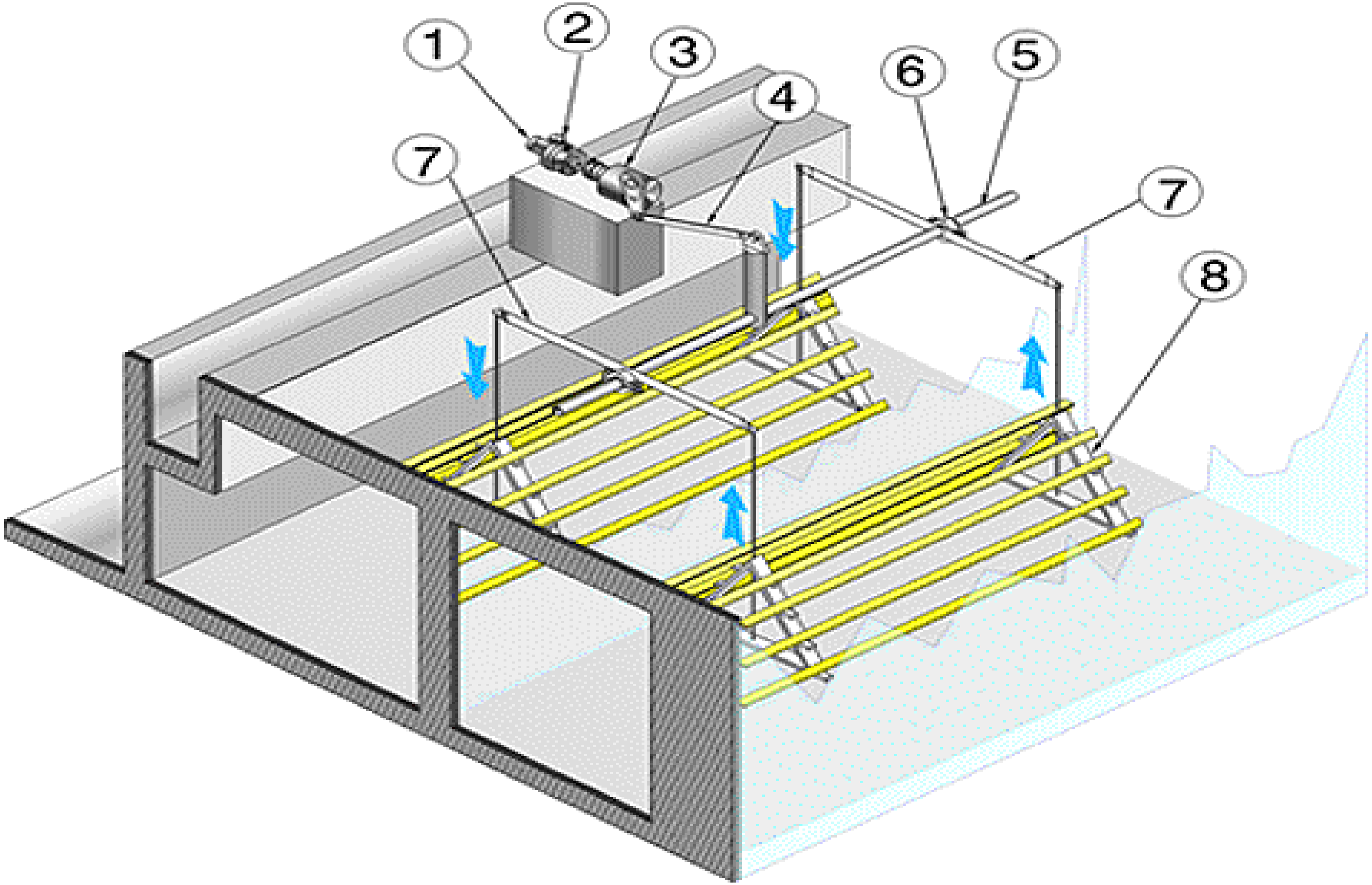




Mechanical flocculators



Mechanical flocculators



Design of mechanical flocculators

- Taken into account
  - Velocity gradient (G):- Mixing intensity
    - » *The degree of mixing is measured by* **Velocity Gradient (G)**
    - » *relative velocity of the two fluid particles/distance*
  - the detention time (t)
- The product G.t gives a measure for
  - the **number of particle collisions**, and thus for the **floc formation action**

The equation for computing the velocity gradient is:

$G = (P/(V.M))1/2$ in which

G= velocity gradient (s^{-1})

P = power transmitted to the water (watt = rghQ)

r = density of water = 1000 kg/m^3

g = gravitational acceleration = 9.81 m/s^2

h = head loss of the water passing through the flocculator in m

Q= volumetric flow rate in m^3/s

V = volume of water to which the power is applied; where applicable, the volume of the mixing tank or basin (m^3)

m = dynamic viscosity of water (kg/m.s),

Dynamic viscosity of water m (kg/m.s)

Temperature t(0C)	15	20	25
Dynamic viscosity μ (kg/m.s)	$1.14x10^{-3}$	$1.01x10^{-3}$	$0.96x10^{-3}$

Flocculator design criteria

Design factor	G(s-1)	t(s)	G.t
Range	10-100	1,200-1,800	30,000-150,000
Typical value	45-90	1,800	50,000-100,000

- the **optimal G.t** value should be carefully selected

- for **optimal formation of flocs** without causing disruption or disintegration

- Chemicals such as activated silica or polyelectrolyets (coagulant aids) can improve the internal cohesion of the flocs

Power Calculation

What horsepower level do we need to supply to a flocculation basin to provide a G value of $100s^{-1}$ and a Gt of 100,000 for 10 MGD flow? **(Given:** M = 0.89×10^{-3} Pa.s ($gcm^{-1}s^{-1}$); 1 hp = 745.7 watts)

Solution:

Retention time, t = Gt/G = 100,000/100 = 1000 secs

Volume of Flocculation basin, V= Q/t = ($0.438\ m^3$/sec) x (1000 sec)
= $438\ m^3$

G = (P/(V.M))1/2

P = G^2 V x M
= 100^2 x 438 x 0.89 $x10^{-3}$ = 3900 W
= 3900/746 = 5.2 hp

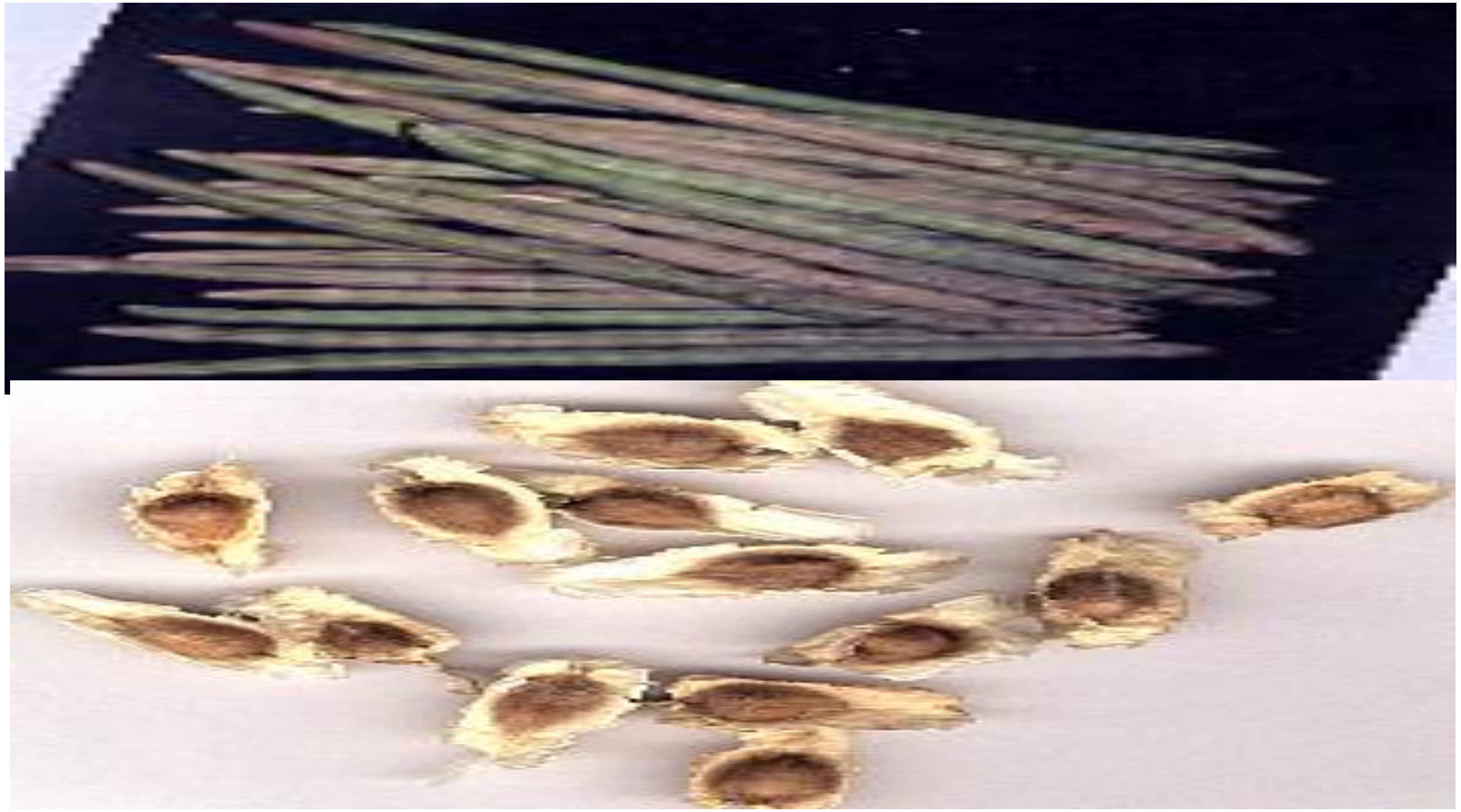
II. Natural coagulants

- has been practiced **for centuries**

Seeds of the *Moringa oleifera* tree have been found to be one of the most effective

Moringa oleifera tree with fully grown ripe seed pods

Moringa Oleifera
seed shells & dry seeds



For 20 litres of water one needs 10 seeds, roughly.

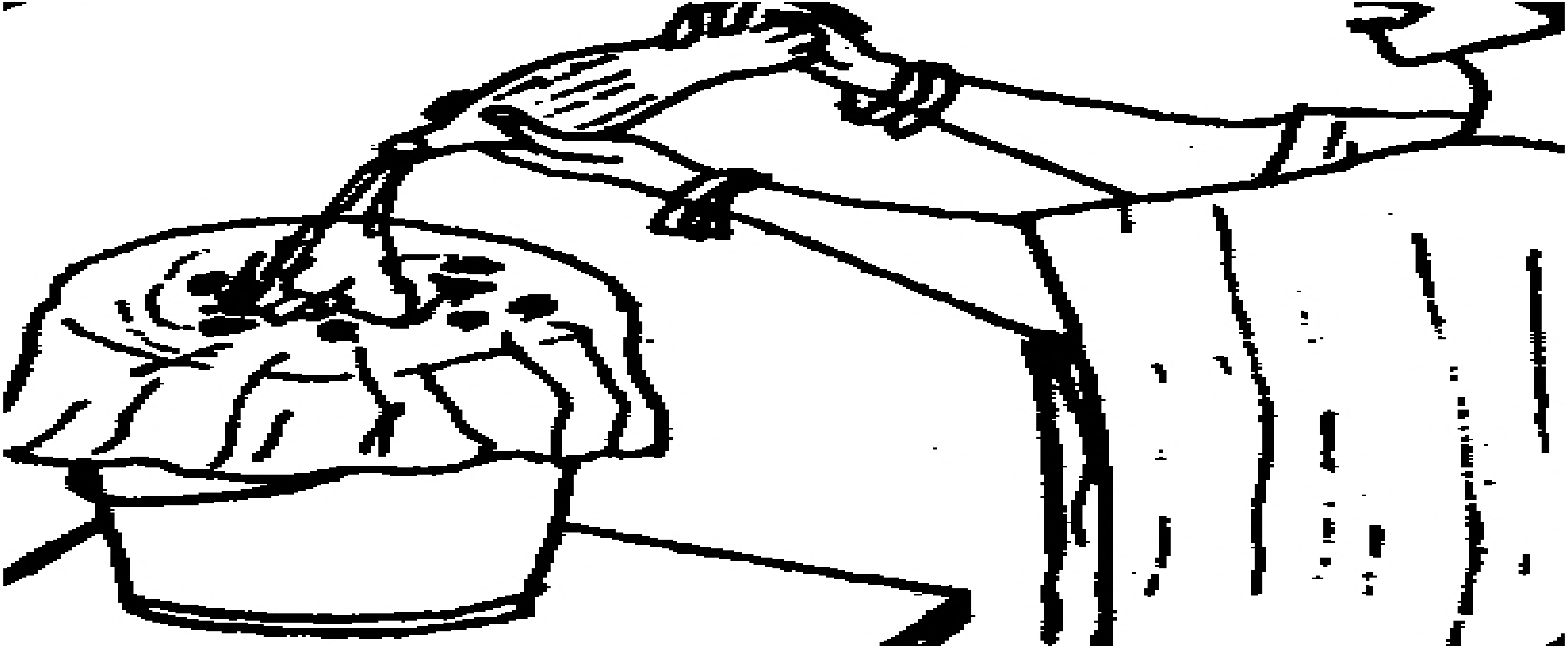
Procedure

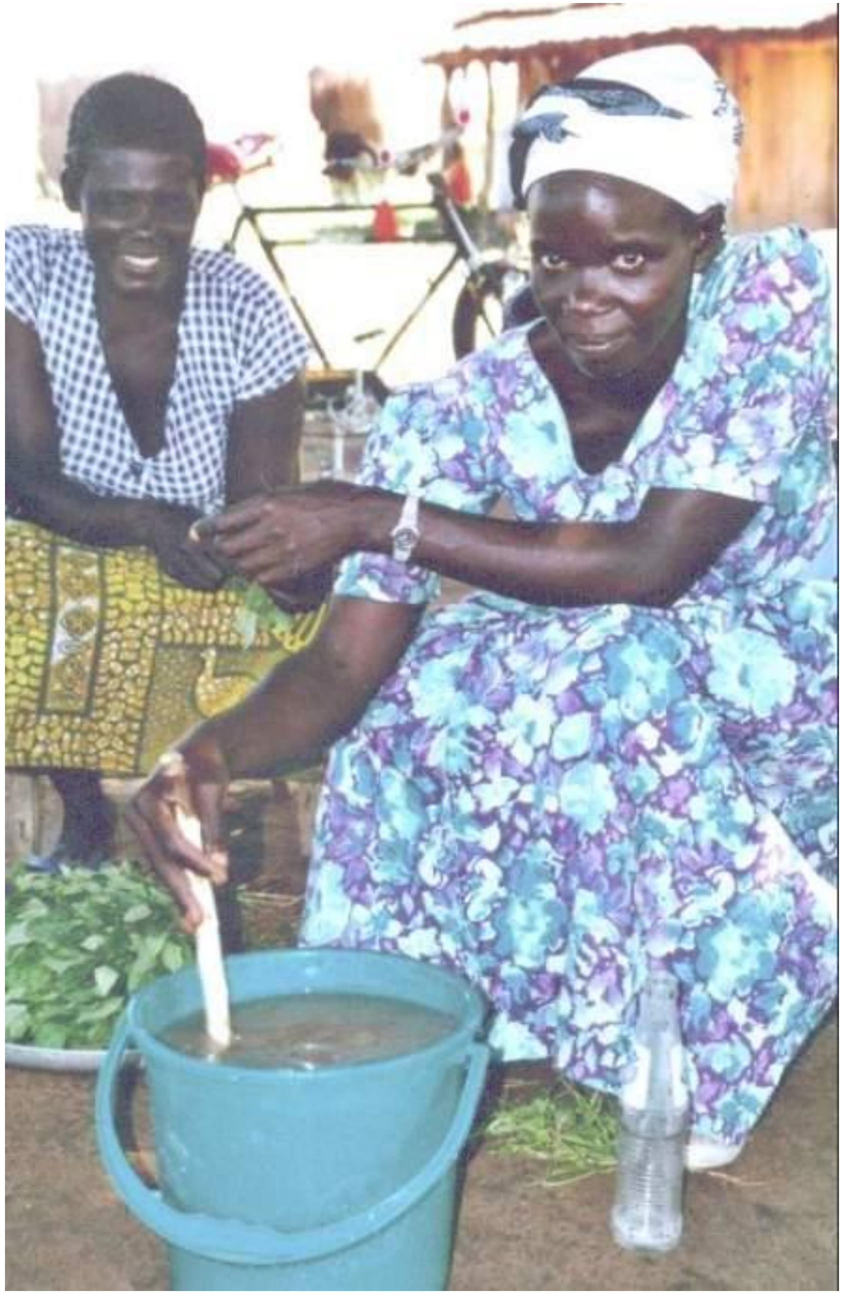
1. Remove the shells.

2. Pound the white seeds.

3. Put the pounded seeds into a bottle with a little clean water and shake vigorously for 5 minutes.

4. Pour through a sieve





5. Stir slowly for 15 minutes

6. and wait!

- *Moringa oleifera* seeds treat water on, **two levels:**
  - **acting as a coagulant**
    - coagulant due to **positively charged**, water-soluble proteins, which bind with negatively charged particles

The chain is long enough to allow active groups to bond to multiple colloids

- **as an antimicrobial agent**
  - by **coagulation** as well as acting directly as **growth inhibitors**

- there is **ongoing research being conducted** on the nature and characteristics of these components

- it is accepted that treatments with Moringa solutions will **remove 90-99.9% of the impurities in water**

differences between alum and Moringa oleifera

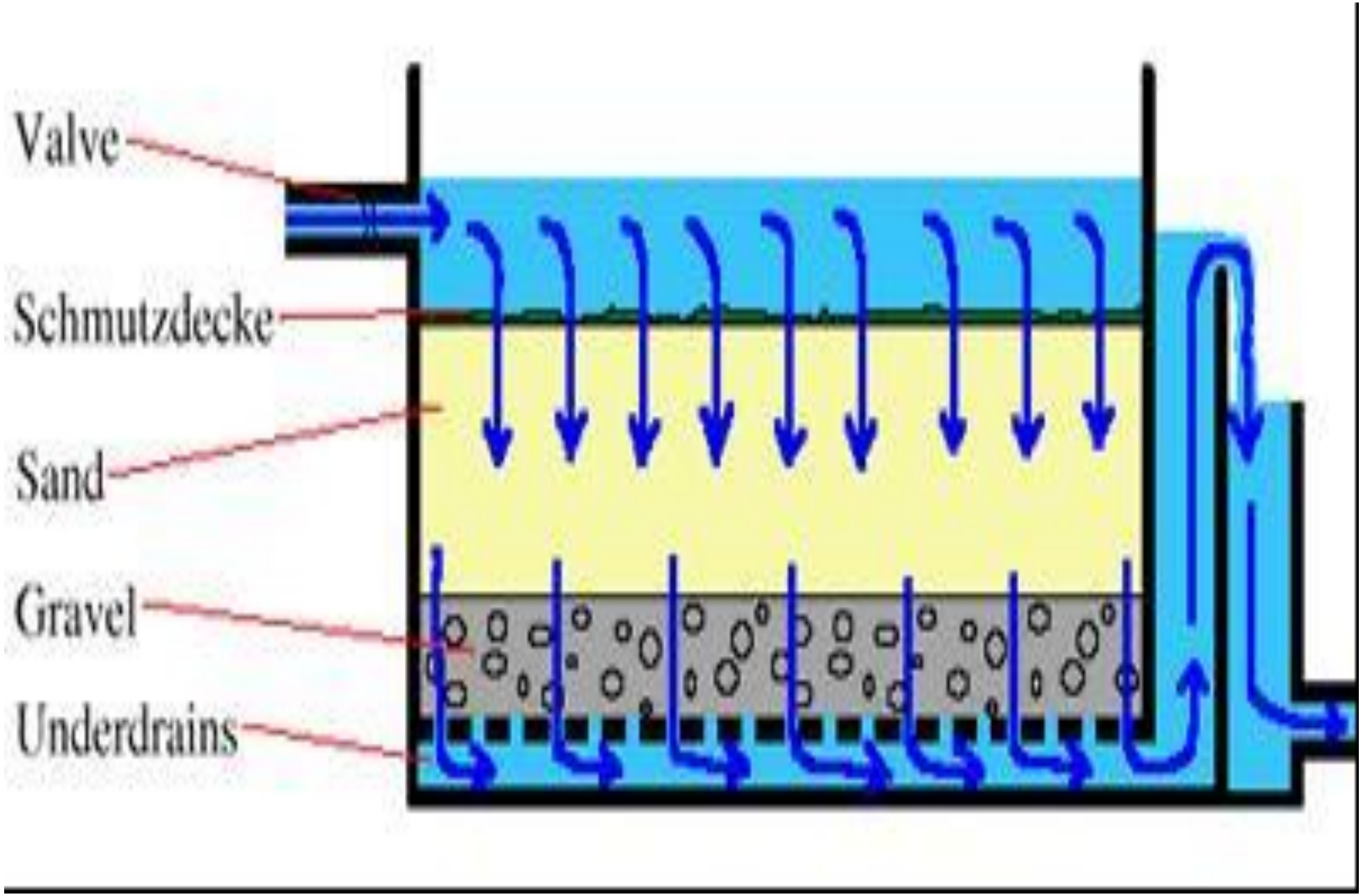
Parameters	Aluminium sulphate	Moringa seed extract
Destabilization	A13+	cationic Polyelectrolytes
Support of aggregation	adsorption at A1(OH)3 flocs	none
Efficiency at low turbidity	still satisfactory at 3 NTU	failing below 30 NTU
Mineralogical nature of suspended matter	minor impact on optimal doses	doses about 50% lower if montmorillonite clays are present (Blue Nile)
Pollution by organic matter	minor impact on optimal doses	great impact on doses and additional organic load
Floc	coarse due to aluminum hydroxides	very fine; result is slower setting; further decrease of settling at lower temperature
Sludge volume	great	small
pH of treated water	increase of acidity (effect of SO42)	no change
Hardness	increase of Ca2+due to neutralisation	no change

2.2.5.Filtration

- a physical, chemical, and biological process for separating suspended impurities from water by passage through porous media

- Two general types of filters are used in water treatment:
  - Slow sand filter and
  - Rapid sand filter

- A slow sand filter consists of a layer of:
  - **ungraded, fine sand**
  - water is **filtered at a low rate;**


Valve
Schmutzdecke
Sand
Gravel
Underdrains

- low rate of filtration allows the formation of an active **layer of microorganisms** called the **schmutzdecke**;
    - which provide biological treatment

- Schmutzdecke of the filter is capable of reducing
    - the **total bacteria count** by a factor of **10^3 to 10^4**
    - **E.coli count** by a factor of **10^2 to 10^3**
    - break down **organic matter**
    - also **fill the interstices** of the sand so that solid matter is retained quite effectively.

- The impurities present in the raw water are removed almost entirely in the **upper 0.5 to 2 cm of the filter bed**

- most practical in the treatment of water with turbidity **below 50 NTU**
  - **best purification occurs below 10 NTU**

- When higher turbidities, SSF should be preceded by some type of **pretreatment**.

SSF advantages for developing countries

1. The cost of construction is low
2. Simplicity of design and operation
3. The labor required for maintenance can be unskilled
4. Imports of material and equipment can be negligible and no chemical are required
5. Power is not required if gravity head is available
6. Variation in raw water quality and temperature can be accommodated provided turbidity does not become excessive; overloading for short periods does no harm.
7. Water is saved

Disadvantage of SSF

1. Large land requirement (about five times that required for rapid filtration plants);
2. Higher construction costs in countries where construction methods are largely mechanized and labor is expensive;
3. Higher costs for cleaning the filters in countries where manual labor is expensive;
4. Need to cover the filters in freezing climates (it is also difficult to find people who will work at cleaning in cold weather);
5. Working of the biological layer (i.e., schmutzdecke) may be upset by certain types of toxic industrial wastes or heavy concentrations of colloids; and
6. Certain types of algae may interfere with the working of the filters, usually choking the filter bed, which calls for frequent cleaning.

Design characteristics slow sand filtration units

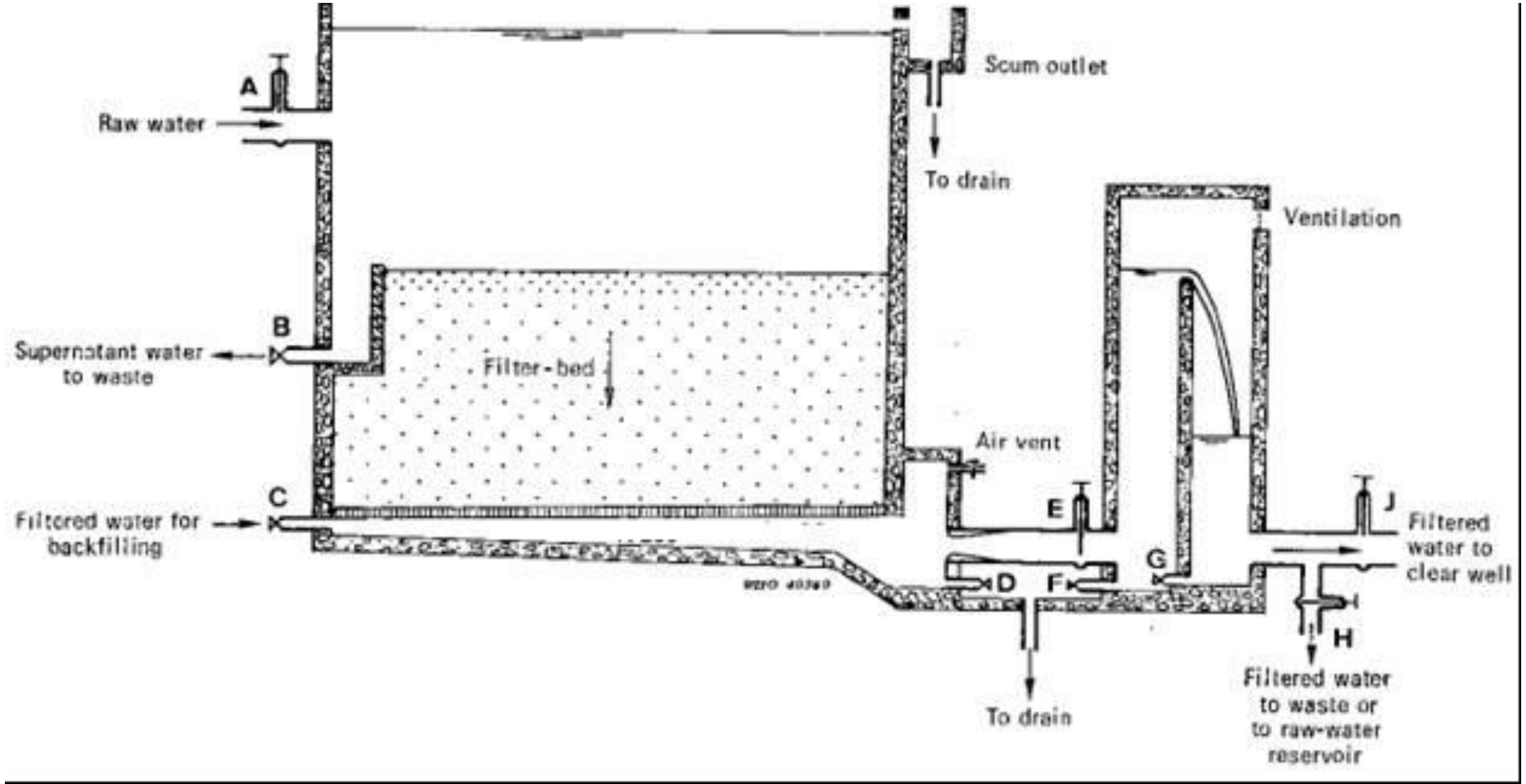
- at least **two units** should operate in parallel for continuous supply

A unit basically consists of a structure that contains:

  - Flow control
  - Drainage systems
  - Supernatant water layer and
  - A filter bed.

Flow control

- **to maintain the proper filtration rate**
- Two types of flow rate control are used:
    - » **Outlet controlled flow**
    - » **Inlet controlled flow**



Drainage system of SSF

- consists of a **principal drain with lateral branches**
- constructed in **perforated pipes**, brickwork or tiles and covered with a layer of graded gravel and a layer of coarse sand.

Functions:

- **Support the filter material** and prevent it from being drained from the filter;
- Ensure **uniform abstraction** of the water over the filter unit;
- Allow for the **backfilling of the filter with clean water** and drive out possible air pockets;

Supernatant water layer

- Provides the **static head**
- Clean bed the initial **head loss** is usually below 0.1m
  - it gradually **increases** until the maximum level is reached

Filter bed

Size grading, characterized by:

- **The effective size of the sand diameter d10**
  - The particle size in which **10 percent of the sand** is smaller
  - there is a reasonably consistent relationship between **the size** and **sand permeability**

- **The uniformity coefficient, UC = d60/d10.**
  - is the **ratio of two particle** sizes: the 60 percent finer size and the effective size

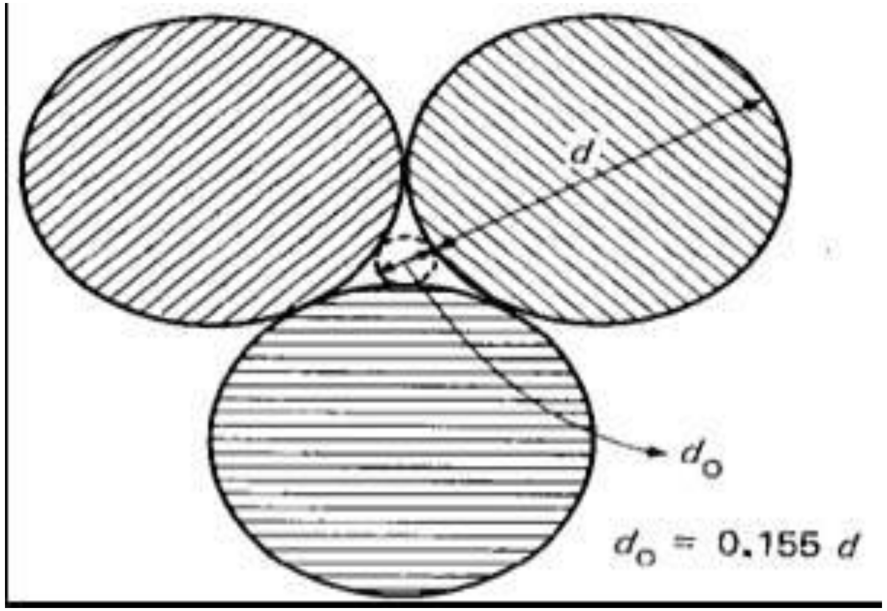
d10 should be small enough:

- to **produce safe water** and
- to **prevent penetration of clogging** matter to such depth that it cannot be removed by surface scraping

- Experiences in the USA report a **total coliform removal** reduction
  - from **99.4% at d10 of 0.1 mm** to

    96% at d10 of 0.6 mm.

relation between grain size and pore size

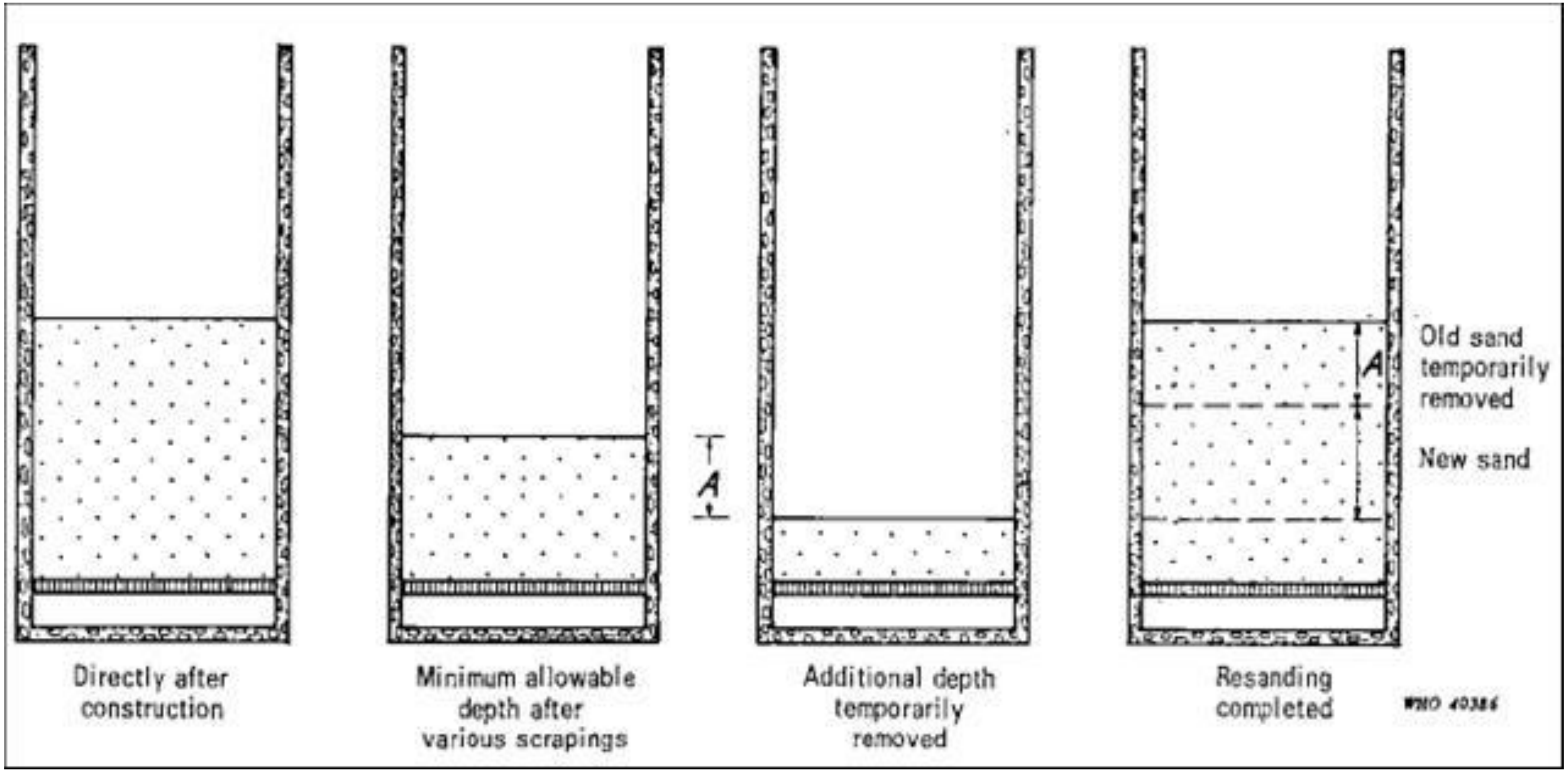


- **Not only the size of grai**n but also **deeper sand beds**

should result in improved removal of particles

Operation and maintenance procedures

- SSF units **must operate continuously**
- After **several weeks** or months of running
    - clogged
- **scraping the top 1-3 cm** of the filtering bed
- minimum depth (**0.3-05 m**), **resanding** is required
- Scraped sand should be **washed and stored**


Old sand temporarily removed
New sand
A
A
Directly after construction
Minimum allowable depth after various scrapings
Additional depth temporarily removed
Resanding completed
WHO 40384

High frequency of scraping is associated:

- High solids concentration in the raw water
- Growth of algae in the supernatant water
- Small media grains
- Low available head and
- High water temperature.

Design guidelines

It depends on:

- Drinking water quality standards,
- Raw water quality,
- The type and level of pre- treatment specified
- The local conditions. These conditions include
  - institutional development and
  - support capacity to community – based organizations
  - availability of materials and financial resources
  - user income, and willingness to contribute to capital investment and
  - running costs of the water supply infrastructure.

SSF design guidelines

Design criteria	Recommendation
Design period (years)	8 – 12
Period of operation (hd-1)	24
Filtration rate (mh-1)	0.1 – 0.3
Sand bed:-	
- initial height (m)	0.8
- minimum height (m)	0.3-0.5
- effective size (mm)	0.15 – 0.30
- uniformity coefficient: acceptable	< 4
- uniformity coefficient: preferred	< 2
Support bed. Height including drainage (m)	0.25
Supernatant water. Maximum height (m)	0.75
Freeboard (m)	0.1
Maximum surface area (m2)	< 100

Treatment efficiencies of slow sand filters

Water quality parameter	Performance or removal capacity
Enteric bacteria	90-99.9%
Enteric viruses	99-99.99%
Giardia cysts	99-99.99%
Cryptosporidium	> 99.9%
Cercaria	100%
Turbidity	< 1 NTU
Pesticides	0-100%
DOC	5-40%
True colour	25 – 40%
TOC; COD	<15-25%
AOC	14-40%
Iron, manganese	30-90%

SSF limitations:

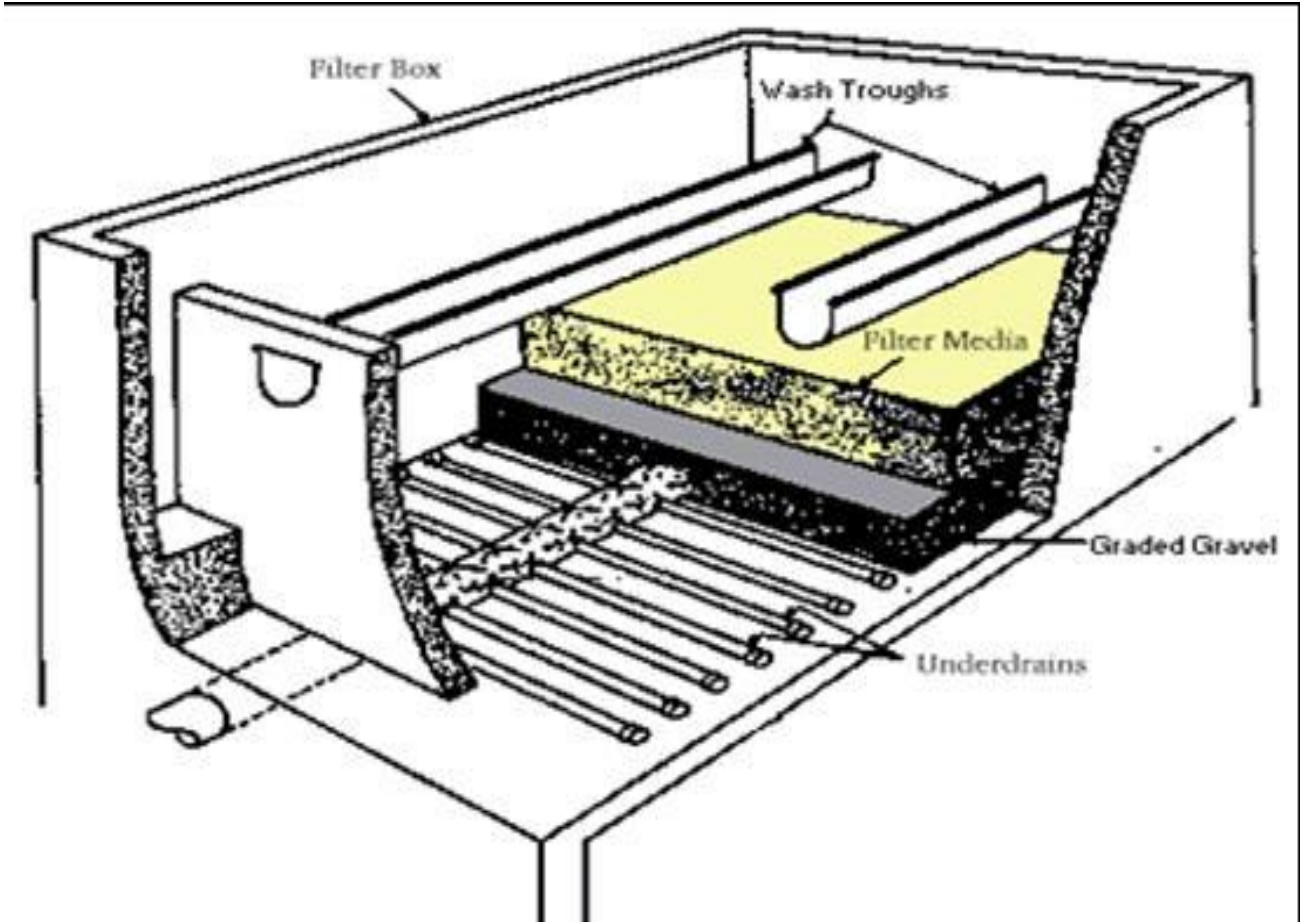
1. Levels of contamination in the raw water may **exceed the treatment capacity**
   - Suspended solids or turbidity
   - Iron and manganese
   - Algae
2. Conditions that **inhibit or reduce the efficiency** of the treatment process
   - low temperatures,
   - low nutrient content
   - low dissolved oxygen content

To Overcoming the water quality limitations

- Multi – stage and integrated water treatment principles

Rapid filtration

- **coarser sand** is used with an effective grain size in the **range 0.4-1.2 mm**
- **pores of the filter bed** are relatively large
- **filtration rate is**, generally between 5 and 15 $m^3/m^2.h$
- Impurities **penetrate deep**
- mostly built open with the water passing down the filter bed by gravity.


Filter Box
Wash Troughs
Filter Media
Graded Gravel
Underdrains

Removal mechanism in rapid filtration

- **A. Mechanical Straining:**
  - particles that are too large pass through the pores of the filter bed

B. Sedimentation

• by **precipitation** up on the sides of the sand grains

• With a pore space P, one m^3 of filter sand with a diameter d has a gross **surface area of**

$$6/d\ (1-P)m^2$$

For a **normal porosity of 40%** and a **diameter of 0.2 mm**, this **gross area amounts to no less than 18000 m^2 per m^3** filtering material.

C. Adsorption:

- Removing impurities by gathering onto the surface of sand grain.

- **Most important purification** process
- Adsorption is effected in two major ways:
  - **Passive adsorption**:**-** is retained on the **sticky gelatinous** coating formed previously deposited bacteria and organic matter.
  - **Active adsorption**:**-** by the **physical attraction** between two particles of matter (Van der waals forces) and the electrostatical attraction between opposite electrical charges (Coulomb forces).

clean **sand has a negative charge**

☟

able to **adsorb positively charged particles** such as – iron & Aluminum hydroxide flocs; iron, managanese ions,

☟

by which the charge of the coating reverses and **becomes positive**

☟

Negatively charged particles such as bacteria & anions of $NO^{3-,}$ PO^{4-} , etc. may now also attracted till again the over all **charge reverses**

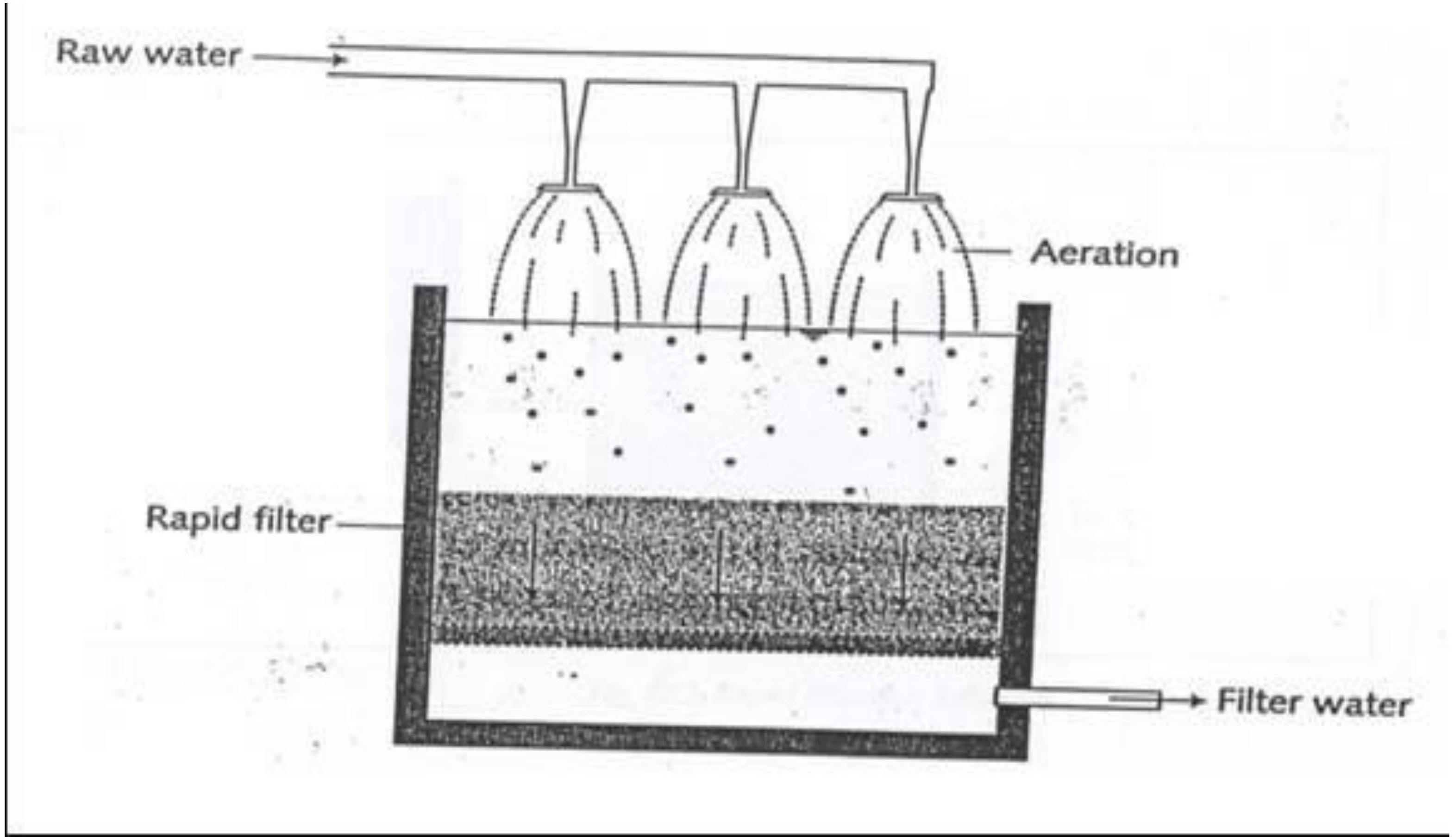
☟

Again adsorb positively charged particles

- Due to **ever changing sequence of – vely & +vely changed**
  - able to **adsorb all impurities** from the passing water.

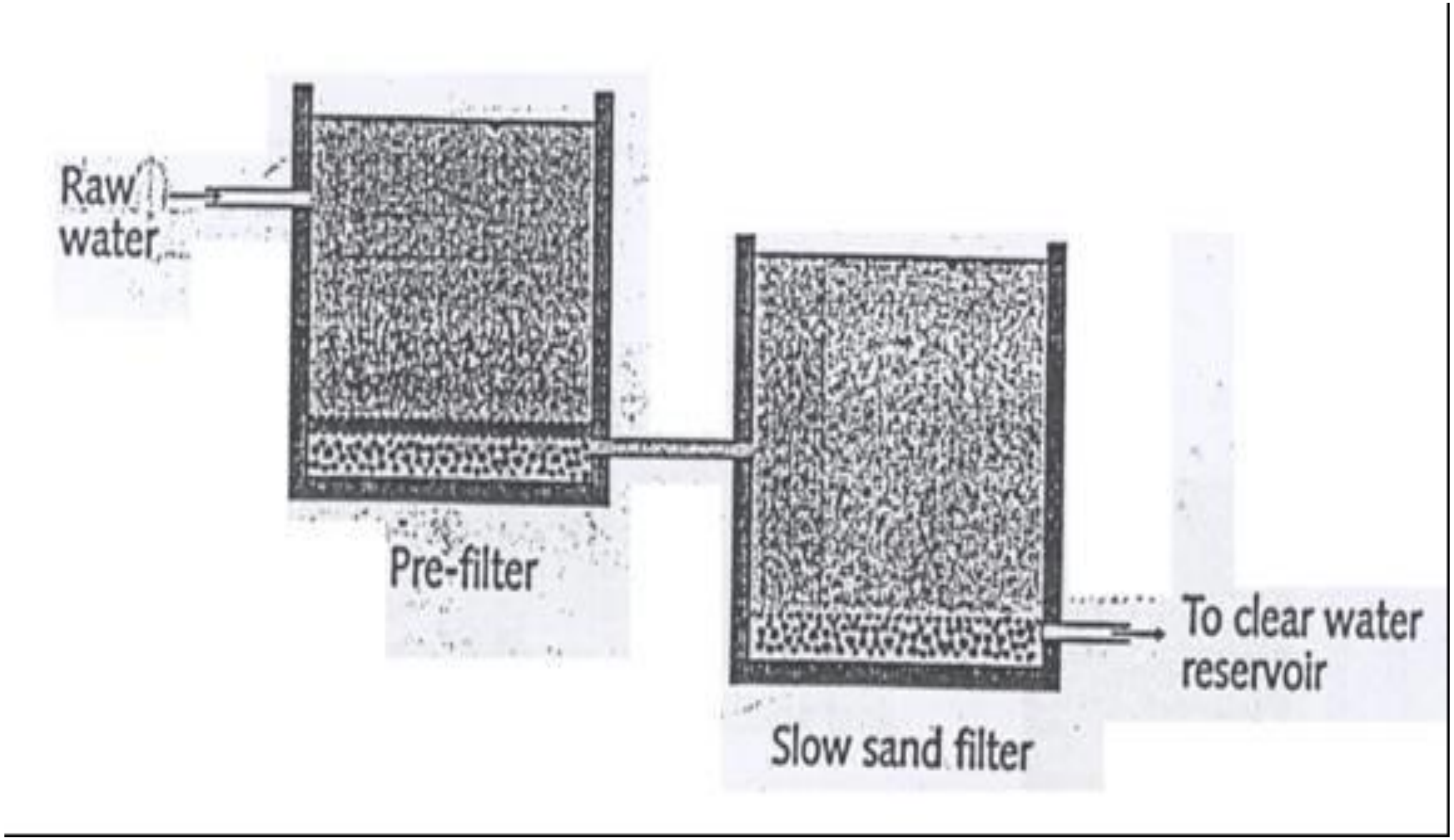
Application of rapid filtration

Rapid filtration of pre-treated (aerated) water

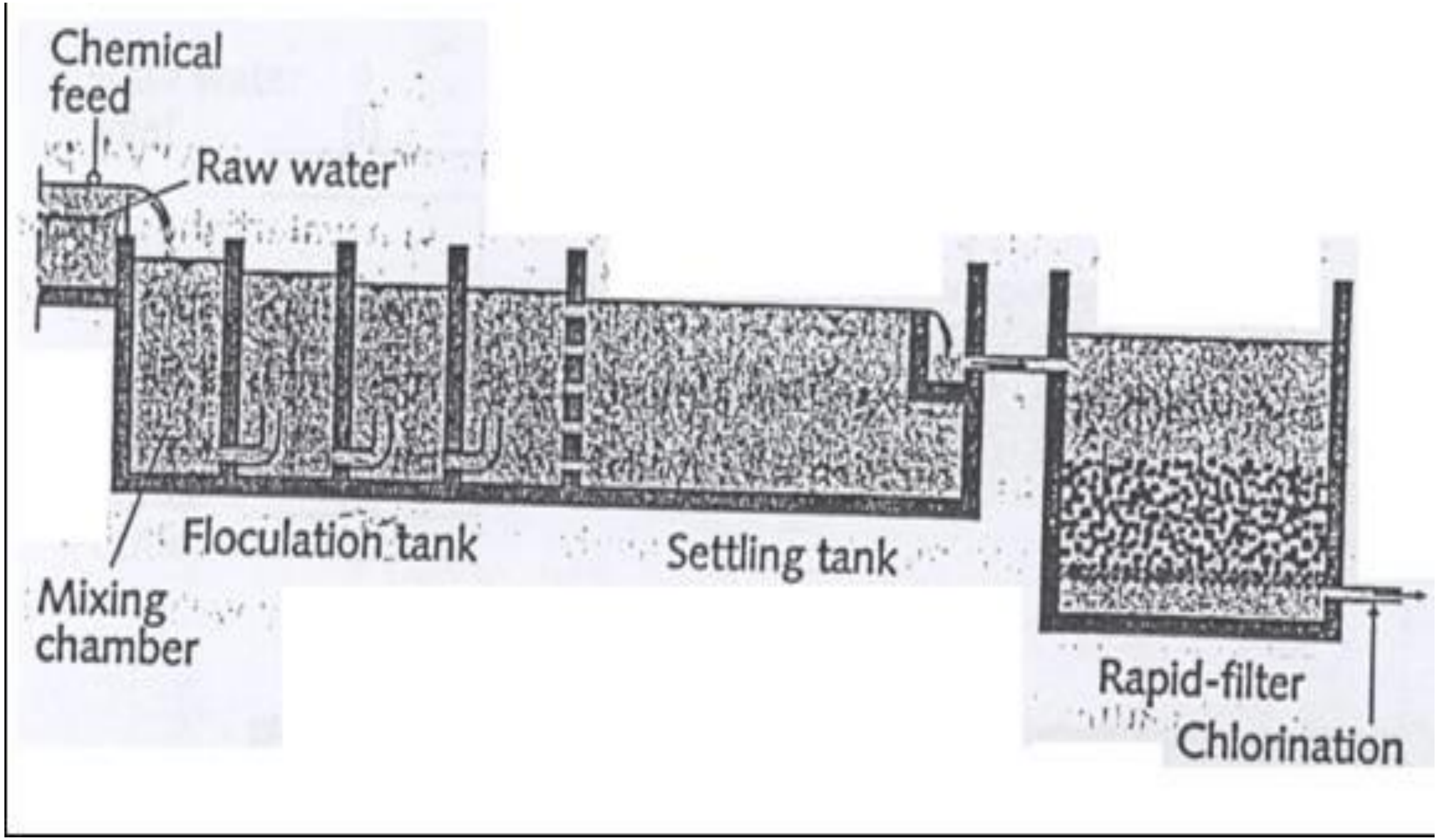


Rapid filtration followed by slow sand filtration

- treatment of river water with high turbidity, rapid filtration may be used as a pretreatment



Rapid filtration after coagulation and flocculation, and sedimentation



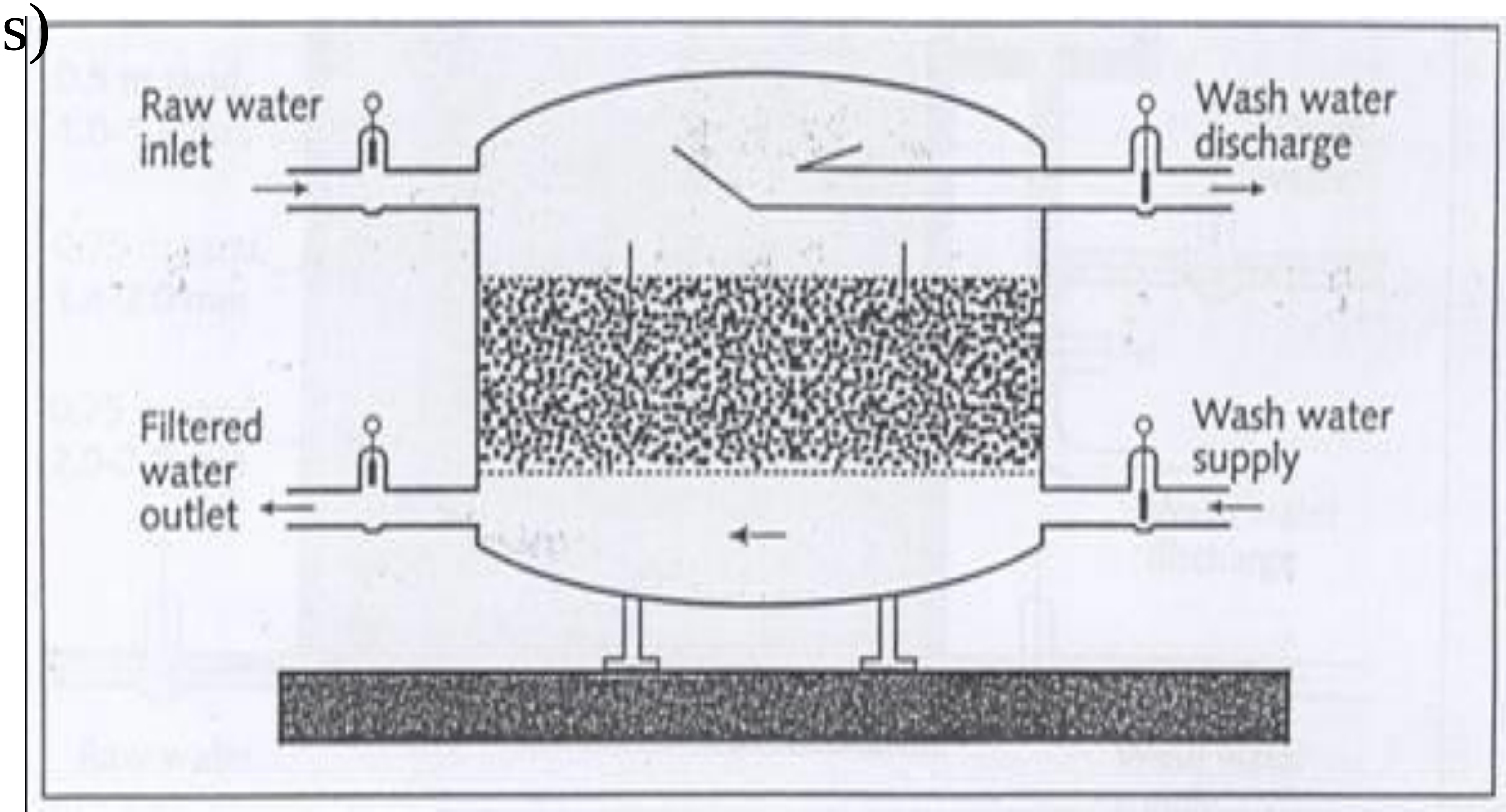
Types of rapid filters

Rapid filters may be classified according to:

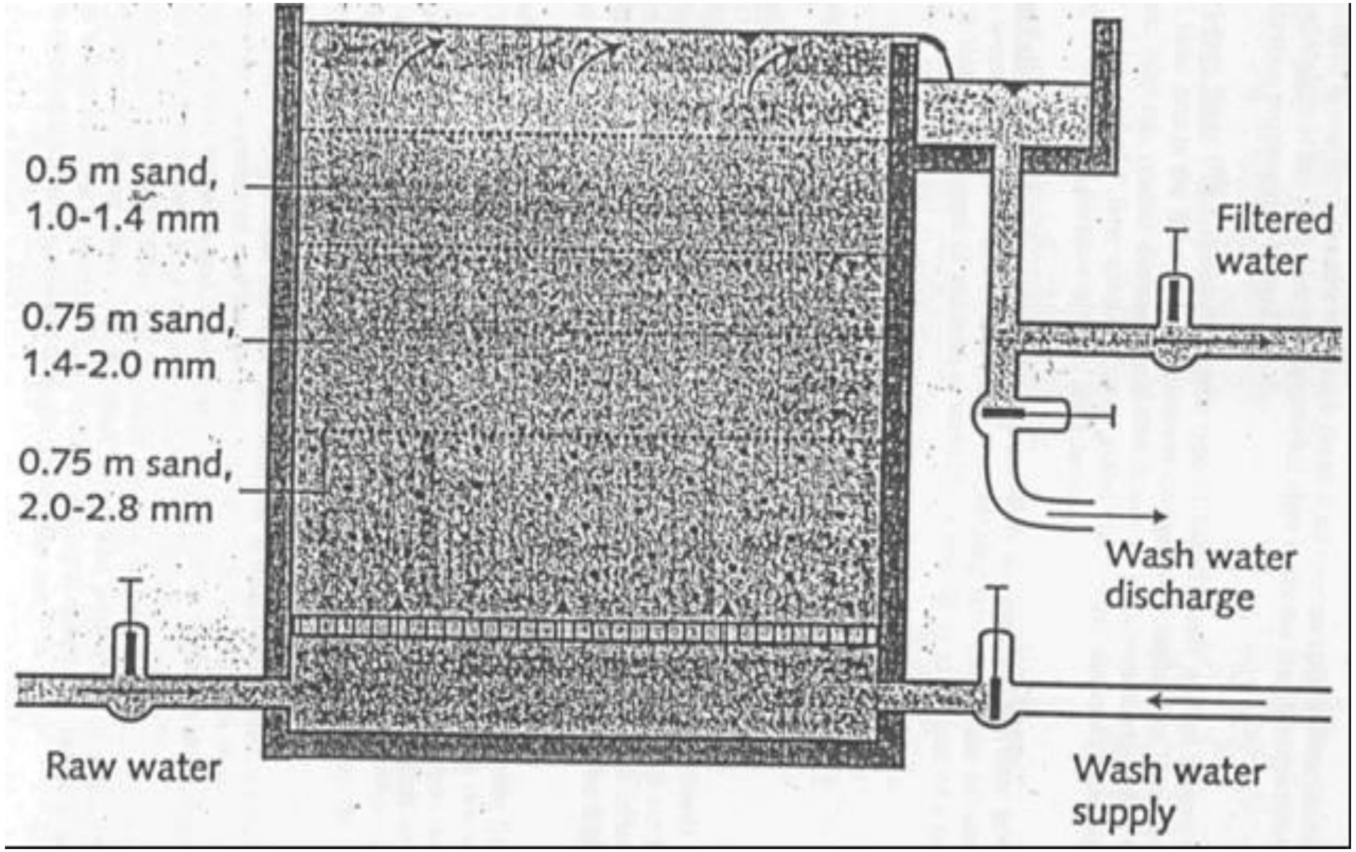
- **Hydraulic head**: gravity or pressurized filter
- **Flow direction**: up flow or down flow filter
- **Filtration rate**: constant or declining filter

Pressurized filter

- watertight steel pressure vessel
- commercially available as complete units
- not readily possible to inspect the condition of the media (dis)



Up flow filters



- **coarse-to-fine** filtration process
- frequently **used for the pre-treatment**
- **hygienic objections** to using them as a final (dis)

Rapid filter operation and control

During filtration the water enters the filter & moves down towards the filter bed

☟

Flows through the filter bed

☟

Passes the under drainage system (filter bottom)

☟

But, due to gradual clogging of the pores the filtration rate decrease

☟

Compensated by a rising raw water level

☟

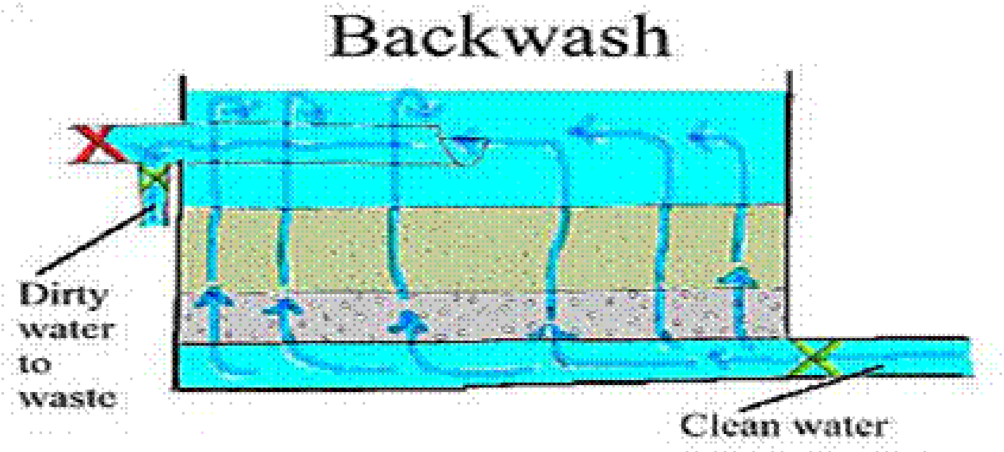
Further clogging of the filter bed cannot be further compensated and the filtration rate will fall.

☟

Backwashing

Backwashing arrangement

- high-rate flow of water back through the filter bed
- **carries away** the deposited material
- can be done as **frequently as required**, if necessary **each day**
- to **decrease the consumption of filtered** water production
  - improving the **pre-treatment** in the sedimentation stage
- For fine filter bed material => **air and water** for good scouring action



For a filter bed of sand (specific weight: 2.65 g/cm^3) typical backwash rates giving about **20% expansion** are listed in table.

d(mm)	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2
T (^{o}C)	Backwash rate ($m^3/m^2/h$)								
10 ^{o}C	12	17	22	28	34	40	47	54	62
20 ^{o}C	14	20	26	33	40	48	56	64	73
30 ^{o}C	16	23	30	38	47	56	65	75	86

Design considerations

For the design of a rapid filter, **four parameters** need to be selected:

- The grain size of the filter material;
- The thickness of the filter bed;
- The depth of the supernatant water;
- The rate of filtration.

- **design factors** should be based on **experience obtained**

- If, experience does not exist **pilot plant operating** experimental filters

Indicative design ranges for rapid filtration

Design parameter	Down flow RSF using conventional sand	Down flow RSF using uniform sand	Up flow direct filtration
Grain size of filter medium	Grain size: 0.45 - 2.0 mm Effective size: 0.45-0.55 mm	Grain size: 0.84-1.68 mm Effective size: 1.0 - 1.2 mm	Grain size: 0.59 - 2.0 mm Effective size: 0.75-0.85 mm
Filter bed thickness	0.6 - 0.8 m	0.8 - 1.2 m	1.6 - 2.0 m
Supernatant water depth	0.6 - 2.0 m	0.8 - 2.5 m	Not applicable
Filtration rate	5 -7.5 m/h	7.5 - 12,5 m/h	5 - 10 m/h
Support layer thickness	0.4 - 0.6 m	0.3 - 0.5 m	0.6 - 0.8 m

Rapid filtration plant layout

- plant consists of a number of filter units (**minimum 2**), each with an **area A**
- one filter **in cleaning**, the **remaining units** must be able to provide the required **capacity Q** at the selected **rate of filtration r**
- This is expressed in the formula:

$$Q = (n-1)\ A \times r$$

Disinfection

- the **destruction**, or at least the **complete inactivation**
- **last barrier** in water treatment

Why disinfection?

- To assure that the bacteriological safe
  - Processes such as storage, sedimentation, coagulation and flocculation, and filtration **reduce the bacterial** content of water to varying degrees.

Factors influence the disinfection of water

- The nature and number of the micro-organisms to be destroyed
- The type and concentration of the disinfectant used
- The temperature of the water to be disinfected
- The time of contact
- The nature of water to be disinfected
- The pH of the water
  - Chlorine will have better disinfection power if pH < 7
- Mixing

Ways of disinfecting water:

Two possible ways of disinfecting water:

1. **For scattered population**
   - disinfection can be applied at **household level**
2. **For higher population density**
   - a "**central**” water disinfection system is more efficient

Disinfection methods

- There are two methods: **Physical and chemical disinfection**

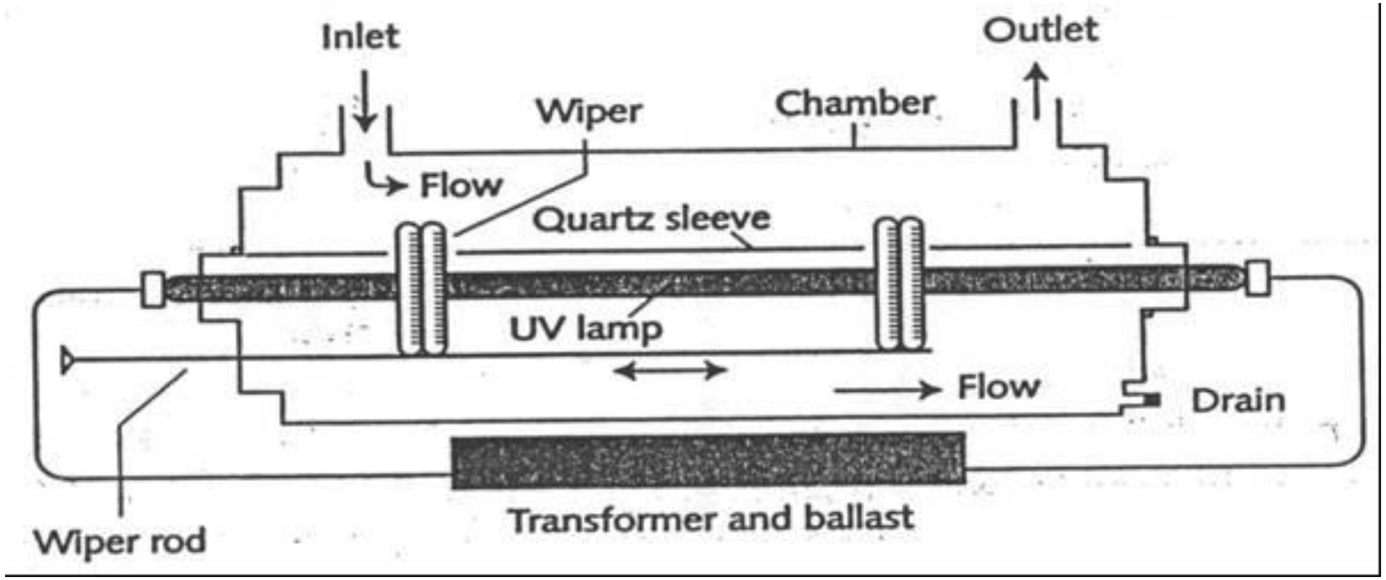
I. Physical disinfection

At family level the two principal physical disinfection methods used are:

- boiling of the water and
- Solar disinfection.

- **At small community** systems
  - Ultraviolet radiation

Ultraviolet radiation



- simplicity of operation and maintenance
- no need to buy and store any chemicals
- no bad taste or odour in the water and
- carries no risk of overdose
- effectively destroys bacteria and viruses.

Limitations ultraviolet radiation

- Doubt inactivation of Giardia lambia or Cryptosporidium cysts
- Unsuitable for water with high levels of suspended solids, turbidity, colour or soluble organic matter
- Does not produce any residual

II. Chemical disinfectants

- Several chemicals, **acting as strong oxidants**, can destroy micro-organisms
- this category include:
  - **Hydrogen peroxide** and other metallic peroxides, lime, potassium and calcium permanganate, iodine, bromine, ozone and **chlorine** and its related compounds

- Clean metals like copper, silver, mercury and zinc also disinfect
    - mechanism that is probably related to the **absorption of the metallic ions by the organism**
        - **affects the chemistry of its cell structure**

A good chemical disinfectant for use should also possess the following important characteristics:

- **Quick and effective** in killing pathogenic micro-organisms present in the water
- **Readily soluble** in water in concentrations required for the disinfection
- Capable of providing **residual**
- **Not imparting** bad tastes, odour or colour to the water
- **Not toxic** to human and animal life

- **Easy to detect** and measure in water
- **Not producing** disinfection by - products (**DBPs**)
- **Easy to handle,** transport, apply and control
- Simple or " **appropriate technology**" devices for dosing
- Readily available in far away locations
- Low cost

- Unfortunately there is not one disinfectant that complies with all of those conditions

- Almost all of them fall into a category that could be called “**far from complying**" such as ozone, iodine, bromine, potassium permanganate and metallic ions

- Only a few may be called “**almost complying**” such as chlorine and its compounds.

A brief description some disinfectants of the first group:

Ozone

- a very strong oxidant
- effective in destroying organic matter and in eliminating compounds that give objectionable taste or colour to water
- Nowadays it is used in several important water facilities in the industrialized countries.
- leaves no measurable residual
- leads to the formation of both inorganic and organic DBP
- The high installation and operation costs
    - the need for continuous supply of power and the need for a proper operation and maintenance,

Iodine

- It has an effective bactericide and virucide power over a **wide range of pH**
- In fact, iodine, unlike other halogens, becomes a more **effective virucide as the pH increases**
- widely used **for individual water supplies** and for small batches of water

Dis

- it is more costly (about ten times more expensive) than chlorine.
- have physiological effects on iodine -sensitive people
- The high volatility of iodine in aqueous solution

Bromine

- Compared with chlorine and iodine, bromine is a **more effective amoebic cysticide** throughout the pH range

- Its residual is more persistent that of chlorine
- On the other hand:
    - **Not easily found** everywhere
    - it is **more costly** than chlorine

Potassium permanganate

- This is a powerful oxidizing agent
- has been found to be **effective against cholera vibrios**
- but **not for other pathogens**

Dis

- It **leaves stains in the container** and hence it is not a very satisfactory disinfectant for community water supplies.

Metallic ions

- Several metallic ions (gold, silver, copper, mercury, etc) have germicidal properties called **oligodynamia**.

- Most of them, though, have **drawbacks**:
  - Gold is **expensive**;
  - Copper is good as an **algaecide** but **not so good as a bactericide;**
  - Mercury is **toxic**.

- Silver seems to be the only one to have **relatively good characteristics** for water disinfection.
  - It is **not very toxic** to human beings
  - the **doses used** in water treatment are **very low**, in the range of 20-75 micrograms / liter.
  - dosing it from solutions or by **direct electrolysis** of silver or silver coated electrodes in the running water
  - Residual silver is **not likely to decay easily**
  - it **does not produce** taste, odours, colour or DBPs

Dis

- **Not as quick** as that of other disinfectants
- Not a very good **virucide**
- **Organic** matter or other **salts present** in the water may **hinder its activity**
- **Costs can be tens** or even hundreds of times more expensive than low -cost disinfectants

Chlorine and its compounds

- **massively introduced** worldwide in the early **20th century**

- are **not perfect disinfectants**, **but** they have a number of characteristics that are highly valuable:

  - They have a **broad -spectrum gemicidal potency**
  - **Good persistence** in water distribution systems
  - Equipment needed for dosage is **simple, reliable and low- cost**
  - easily found even in **remote location** in developing countries.
  - It is **very economic and cost effective**

Mechanism

- Chlorine kills pathogens such as bacteria and viruses **by breaking the chemical bonds in their molecules**
- Chlorine compounds which can **exchange atoms with other compounds**, such as enzymes in bacteria and other cells
- When enzymes come in **contact with chlorine**, **one or more of the hydrogen atoms** in the molecule are replaced by chlorine
- This causes the entire molecule to **change shape or fall apart.**
- When enzymes **do not function properly**, a cell or bacterium will die.

The most popular substances in the chlorine families are:

  - Chlorine;
  - Chlorinated lime;
  - High-concentration hypochlorite;
  - Sodium hypochlorite.

- They present different **active chlorine concentrations,** which is a measure of their strength.
- Active chlorine is **the percentage by weight of molecular chlorine that would be rendered by a molecule of the compound**.
  - If for example, a certain solution contains **10% of active chlorine,** this is equivalent to 10 g of chlorine gas being bubbled (and totally absorbed) in 100 ml (100g) of water.

Chlorine

- Chlorine is a **greenish yellow toxic gas**
- found in **nature only in the combined s**tate, chiefly with sodium as common salt.
- It has a **characteristic penetrating and irritating odour**
- **Heavier than air**
- Can be **compressed to form a clear amber-coloured** liquid
- Liquid chlorine **is heavier than water**
- It vaporises under normal atmospheric temperature and pressure.

- Commercially, **chlorine is manufactured by the electrolysis of brine,** with caustic soda and hydrogen as by-products

- **As a dry gas**, **chlorine is non - corrosive** but in the presence of moisture it becomes highly corrosive to all metals except silver, titanium, gold and lead

- Chlorine is **slightly soluble in water**, approximately 1 percent by weight at 100^{o}C.

Chlorinated lime (Bleaching powder)

- **Before the advent of liquid chlorine**, chlorination was mostly accomplished by the use of **chlorinated lime**.
- the approximate composition
  - $CaC1_2.Ca(OH)_2.H_2O + Ca(OCl)_2.2Ca(OH)_2$
- **When added to water**, it decomposes to give hypochlorous acid, **HOCl**.
- When fresh, chlorinated lime has active chlorine content of **33-37%**.
- Chlorinated lime is **unstable**.
  - Exposure to air, light and moisture makes the chlorine **content fall rapidly**.
  - The compounds should be **stored in a dark, cool and dry place; in closed, corrosion-resistant containers**.

High - Concentration hypochlorites

- has active chlorine content of 60-70%
- Can **retain their original strength** for more than a year under normal storage conditions.
- They are available in **granular or tablet form**

Sodium hypochlorite (NaOCl)

- usually contains **10-15%** active chlorine in the commercial product
- Household bleach solutions of sodium hypochlorite usually contain only **3-5%**

Pre-and post - chlorination and disinfection by – products

- At the **end** of the treatment called **post-chlorination**
- **Pre-chlorination** is sometimes applied **prior to any other** treatment.
  - This is done for the purpose of **controlling algae, taste and odour.**
  - In this case and when the raw water **carries some organic materials (called precursors)** it may give place to the production of disinfection by - products (DBPs).
  - The most characteristic constituents of the DBPs are the **Trihalomethanes** (THMs).

Chlorination in practice

- Chlorination is carried out in practice through the **bubbling of chlorine gas** or through the **dissolving of chlorine** compounds.

Chemistry

- In the **case of chlorine gas**, the reaction that takes place is:

$$C1_2 + H_2O \leftrightarrow H^+ + Cl^- + HOCl$$

- In the **case of hypochlorites**, the reaction that takes place is:

$$NaOCl + H_2O \leftrightarrow Na^+ + OH^- + HOCl$$

- Or in the case of **chlorinated lime** (The portion that takes part in the reaction is $Ca(OCl)_2$):

$$Ca(OCl)_2 + 2H_2O \leftrightarrow Ca^{++} + 2OH^- + 2HOCl$$

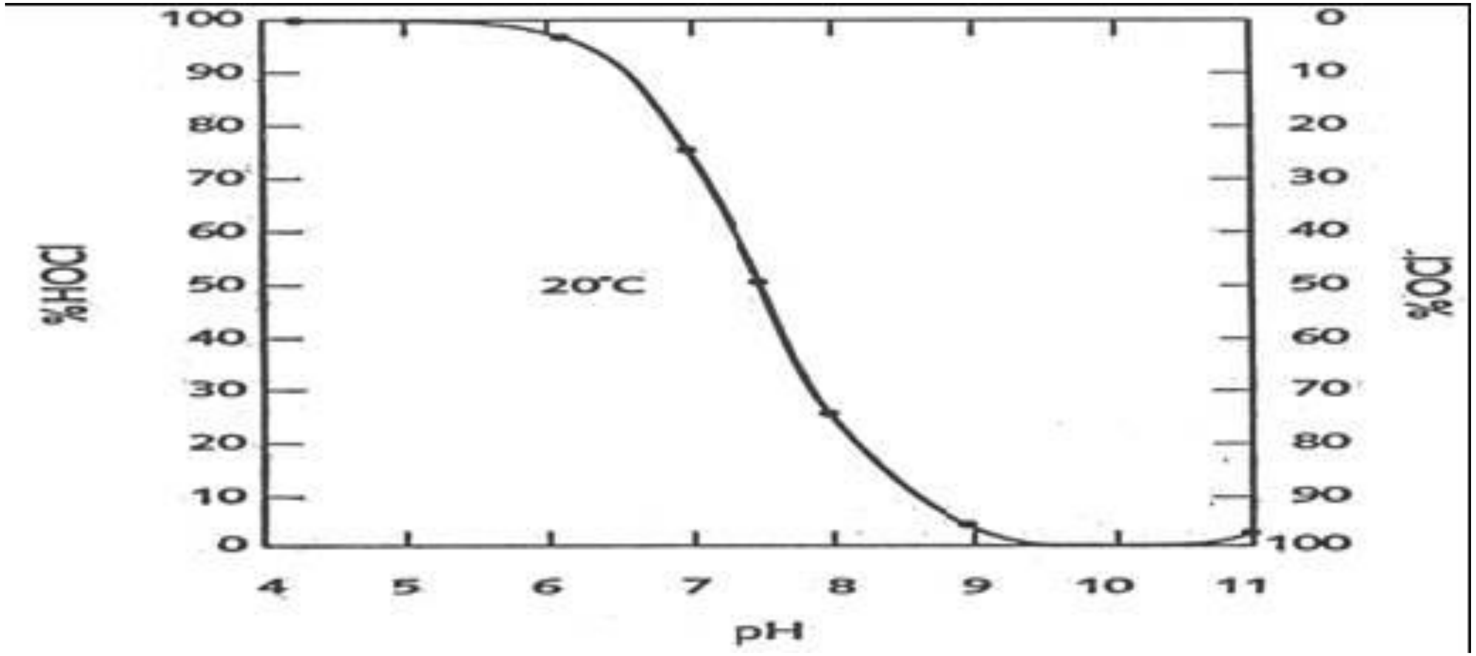
- The HCl and the sodium and calcium hydroxides formed in the different reactions **do not take part in the disinfection process.**

- The Disinfectant Species, the **hypochlorous acid** (HOCl); dissociates in water as follows:

$$HOCl \leftrightarrow H^+ + OCl^-$$

- The **pH of the water will govern** the relative quantities of HOCl and OCl^- .

- Both hypochlorous acid (HOCl) and hypochlorite ion (OCl-) are present to some degree when the **pH of the water is between 6 and 9**

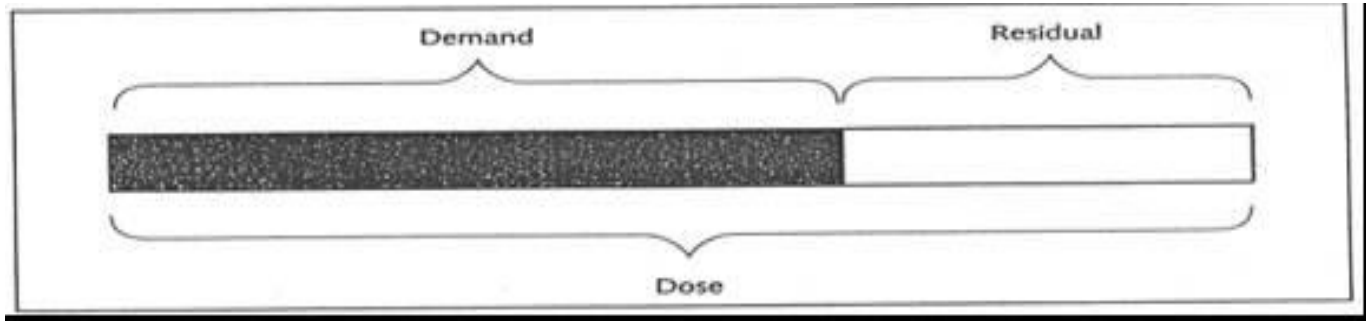


- two compounds have **different germicidal properties**
- the HOCl efficiency is **at least 80 times greater** than that of the OCl-
- Therefore, **in monitoring chlorine in water, the pH also needs to be monitored**

Dose/ Demand / Residual

- **Dose:** The amount of chlorine **added** to the water and usually measured as the number of **milligrams added to each liter of water** (mg/l)
- **Demand**: The amount of chlorine **destroyed in the reaction** with the substances in the water
- **Residual**: The amount of chlorine (either free or combined) that **remains** after a certain contact time

Chlorine dose = chlorine demand + chlorine residual



Minimum contact time is 30 minutes

WHO recommends the following conditions **for a proper disinfection:**

- Residual chlorine: **> 0.5 mg/l**
- Contact time **> 30 minutes**
- pH: **< 8**
- Turbidity: **< 5 NTU**; but ideally **< 1 NTU**

Determination of residual chlorine

- Several methods are available
- Two of the simpler methods are:

1. **Diethyl-para-phenylenediamine method (DPD)**

- **colorimetric** method

- Available free **chlorine reacts** instantly with **N-diethyl-para-phenylenediamine** to **produce a reddish tint**

- The **color produced by this method is more stable** than that of the Orthotolidine method.

2. Orthotolidine method

- Orthotolidine, an aromatic compound, is **oxidized in an acid solution by chlorine**, Chloramines and other oxidants to **produce a yellow-colored complex**
- the **intensity** of which is **directly proportional** to the amount of oxidants present
- The method is suitable for the routine determination of residual chlorine **not exceeding 10 mg/l**.
- The presence of natural color, turbidity and nitrates **interferes** with the color development.
- Orthotolidine has been shown to be **carcinogenic** and should be handled with care.

Peer Group discussion-three

1. Assume that you are a manager of large water treatment plant of big town. This plant use surface water as a source of raw water. Because of budget constrain, you faced difficult to buy sufficient amount of alum for that budget year. What options do you propose to solve this problem?

2. Assume that the raw water contain the following impurities; Suspended solids, Taste and odor, Iron and manganese, Giardia cysts, Carbon Dioxide and large size wood pieces. Design the treatment processes needed to make the raw water potable.

Other Treatment Processes

- Mostly **conventional treatment process is designed** to removal of microorganisms, suspended solids and some of the dissolved impurities.

- Drinking-water, particularly from **groundwater** sources, may also contain **chemical contaminants which must be removed.**

- Generally the **removal of chemicals** from water is **more difficult and much more expensive** than removing microbiological or physical contaminants.

- Basic filtration and coagulation techniques are not generally effective for the majority of chemicals.

Fluoride removal

Guidelines and standards

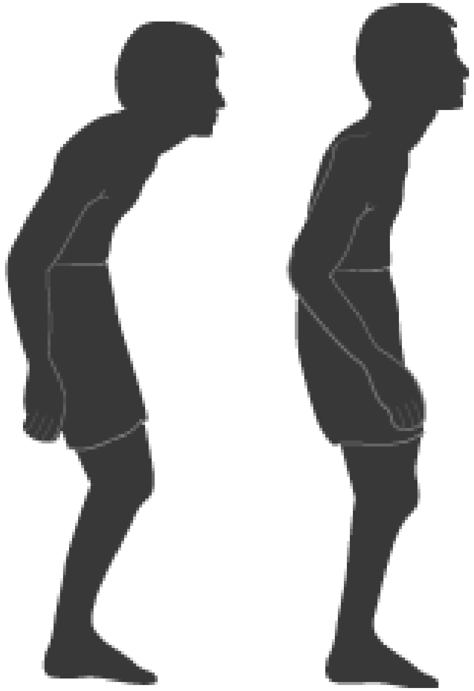
- world Health organization has set a guideline value of **1.5 mg/1** as the maximum permissible level of fluoride in drinking water.
- **However, it is important to consider:**
  - climactic conditions
  - volume of water intake
  - diet and other factors in setting national standards for fluoride.

Health impacts of fluoride in potable waters

Excess→ dental fluorosis (mottled teeth)

→ Skeletal fluorosis

Shortage → dental caries (tooth decaying)



These men in India have developed crippling skeletal fluorosis from fluoride in water

Fluoride control options

I. Search for alternative sources:

- fluoride concentration in a community's water supply is **significantly and consistently beyond the permissible level**

Options are:

(a) Provision of a **new and alternate source** of water with acceptable fluoride levels

(b) **Transporting water** from a distant source

(c) **Blending high fluoride** with low fluoride water:

(d) Dual water sources

- The source having **low fluoride** levels can be strictly limited to. **drinking and cooking**
- The water source with **high fluoride** can then be used for **other purposes**

(e) Rainwater harvesting

- Individual **household-roof rainwater** harvesting
- On harvested surface water run-off can be used to **recharge high-fluoride groundwater sources**

II. Defluoridation of water

- none of the above options is feasible, defluoridation have to be practiced

Defluoridation methods can be broadly divided:

  - Chemical additive methods
  - Contact precipitation
  - Adsorption/ion exchange methods

Chemical additive methods

Example:

Nalgonda technique

- The **use of alum and a small amount of lime**

It involves:

1. **adding lime**
2. **bleaching powder (optional) and**
3. **alum ($Al_2 (SO_4)_3 . 18H_2O$) in sequence** to the water
    - followed by coagulation, sedimentation and filtration.

- A **much larger dose of alum is required** for fluoride removal (**150 mg/mg F^-**), compared with the doses used in routine water treatment.

Contact Precipitation

- Fluoride is **removed form water through the addition of calcium and phosphate** compounds

- The presence of a **saturated bone charcoal** medium acts as a **catalyst for the precipitation** of fluoride either as **CaF_2**, and/ or fluorapatite.

Adsorption/ion-exchange method

- Raw water is passed through a **bed containing defluoridating material**
- **The material retains fluoride** either by **physical, chemical or ion exchange mechanisms**
- The adsorbent gets **saturated** after a period of operation and **requires regeneration**.
- A **wide range of materials** has been tried for fluoride uptake
  - Bauxite, magnetite, kaolinite, serpentine, **various types of clays and red mud** are some of the naturally occurring materials studied.

Iron and manganese removal

- the **concentrations limits** of iron and manganese in drinking water are **not based on health** considerations **but on aesthetic aspects**.

- **Iron over 0.3 mg/l iron**
  - can have a **reddish-brown colour**
  - generate **deposits on plumbing fixtures**.
  - cause a **bitter taste**.
- **Manganese over 0.1 mg/l**
  - **stained laundry** and bathroom fixtures.
  - slough off as a **black precipitate**

- In general one can say **that if there is a problem of manganese in drinking water there will also be a problem of iron in the water**.

- Removal of **iron is less difficult than** removal of manganese.

  - Removal of manganese is almost impossible without either using an **oxidizing agent (which is usually potassium permanganate $KMn0_4$)** or **increasing the pH.**

Removal processes

Removal of dissolved iron:

- Is based on the transformation of the **soluble form** of iron (Fe^{2+}) to the **insoluble form** of iron ($Fe(OH)_3$)

$4Fe^{2+} + O_2 + 2H_2O$ ------> $4 Fe^{3+} + 4OH^-$

$4 Fe^{3+} + 4OH^- + 8H_2O$ ------> $4Fe(OH)_3 + 8H^+$

$4 Fe^{2+} + O_2 + 10H_2O$ ------> $4 Fe(OH)_3 + 8H^+$

For this reaction oxygen is required:

* $4\ Fe^{2+} + O_2 + 10\ H_2O$ ------> $4\ Fe(OH)_3 + 8H^+$

  4×56 mg $Fe^{2+} = 2 \times 16$ mg O_2

  1 mg $Fe^{2+} = 32 / (4x56)$ mg $O_2 = 0.14$ mg O_2

1 mg Fe^{2+} = 0.14 mg O_2

N.B. The pH is decreased due to the formation of H^+

- The rate of oxidation depends strongly on the pH. The lower the pH $\Rightarrow$ the lower the rate of oxidation.

What is happening in practice?

- In practice iron is removed from ground water by: **aration followed by rapid sand filtration.**

- **Subsurface removal is a cheap alternative** for the removal of iron.
  - water is **injected in the soil through a well**.
  - This water is free from iron and contains oxygen.
  - After the **injection of e.g 1000 m^3**, water is abstracted which is free from iron.
  - The quantity of water which is free from iron that can be abstracted in much more than 1000m^3 e.g **up to 10000m^3**

Removal of manganese

- based on the formation of **MnO_2 which in insoluble**. This compound is formed when Mn^{2+} is oxidized e.g. by oxygen;

$6Mn^{2+} + O_2 + 6H_2O$ ------> $2Mn_3O_4 + 12H+$

$2Mn_3O_4 + 2O_2$ ------> $6MnO_2$

$6Mn^{2+} + 3O_2 + 6H_2O$ ------> $6MnO_2 + 12H+$

$1mg\ Mn^{2+} = 0.29\ mgO_2$

- The rate of oxidation in a solution is very low when the **pH is below 8.6**.

Removal of ammonia (NH_4^+) and Nitrate

Ammonia (NH_4^+) removal

- Originates from: Domestic waste (water), Fertilizer, Peat (groundwater) & Industrial wastewater.

- **Effect of NH_4^+ presence:**
  - **Effectiveness of chlorine is affected** due to the formation of **NH_2Cl**
  - After growth may occur in the distribution network, **food for organisms**

The removal methods of NH_4^+

1. Breakpoint chlorination
2. Bio- oxidation, e.g. S.S.F., R.S.F
3. Air stripping

1. Breakpoint Chlorination

- When **more chlorine** is added than equivalent amount **to oxidize ammonia completely into nitrogen (N_2**),
- The overall reaction, which occurs, results from the three reactions together:

I. $2NH_4^+ + 2C1_2$ -----> $2NH_2C1 + 4H+ + 2C1^-$

II. $2NH_2C1 + 2C1_2$ -----> $2NHC1_2 + 2H^+ + 2C1^-$

III. $2NHC1_2$ -----> $N_2 + C1_2 + 2H^+ + 2C1^-$

IV. $2NH_4 + + 3C1_2$ -----> $N_2 + 8H^+ + 6C1^-$

Theses complete reaction is called **chlorine breakpoint reaction**

6 mg $C1_2$ per mg NH_4^+

- When excess of chlorine is added a side reaction occurs:

  $NHC1_2 + C1_2$ ----> $NC1_3 + H^+ + C1$
- The formed $NC1_3$ **has a bitter taste,** so this reaction is not desired.

2. Bio- Oxidation

- Oxidation of ammonium by bacteria follows the equations:

$2NH^{+}{}_{4} + 3O_2$ $\underline{\text{Nitrosomonas }}>$ $2NO_2^{-} + 4H+ + 2H_2O$

$2NO_2^{-} + O_2$ $\underline{\text{Nitrobacter }}>$ $2NO_3^{-}$

$2NH^{+}{}_{4} + 4O_2$ -----> $2NO_3^{-} + 4H^{+} + 2H_2O$

1 mg $NH^{+}{}_{4}$ = 3.6 mg O_2 /l

- The concentration that can be removed by S.S.F. and R.S.F. is **limited by**:

  a) The **available O_2** in water

  b) The presence of **biodegradable organic and inorganic** matter, e.g. CH4; BOD5; Fe2+; Mn2+; NO2- Which consume oxygen

3. Air stripping

- This method is **very expensive as**:
  - **High pH is required** (10 to 11) as the ammonia ion **NH^+_4 have to** be transformed to the **volatile NH_3** compound.

    NH^+_4 + OH^- -----> NH_3 + H_2O

    (Non volatile) (Volatile)

  - And high air to water ratio due to low partition coefficient (NH_3 is very soluble in water)
- **Consequently**
  - High investment costs
  - High energy consumption
  - Chemical costs e.g. Ca(OH)2
  - Clogging occurs due to precipitation of CaCO3

Nitrate removal

- Nitrate in groundwater **originates from**:
  - **Natural biological process in the soil** e.g. plants / bacteria which are responsible for concentration up to **5-10 mg NO_3^-/l**
  - **Oxidation of NH^+_4** in the aerobic zone in the soil.
    - $2\ \mathbf{NH^+_4} + 4O_2$ bacteria $2\ \mathbf{NO_3^-} + 4H^+ + 2H_2O$.
    - This can result into concentration **up to several hundred mg/l.**
  - Domestic solid and liquid waste fecal matter, urine
  - Domestic wastewater
  - Waste of (intensive) animal farming (manure)
  - Fertilizer used in agriculture containing nitrate.

Treatment processes

- Reverse osmosis
- Ion exchange

Reverse osmosis

- When **pure water is separated from a salt solution** by a **semi-permeable membrane**
    - the **pressure on the salt solution** exceeds the **osmosis pressure**

  – **water is transported through the membrane and salts (cations and anions) are rejected**

- Nitrate can be removed from water membranes operate at a pressure between 14 and 70 bars. The rejection of the membranes is between **90 - 99.5%**

Effect of reverse osmosis

Parameter	Raw water	Product
NO_3^-	50mg/l	7 mg/l
Cl^-	23 "	3 "
$SO_4^=$	18 "	3 "
HCO_3^-	2.9 mmol/l	0.1 mmol/l
Ca^{2+}	3.3 "	0.1 "
pH	7.2 "	4.6 "

Disadvantage reverse osmosis

- Costly
- Discharge of brine

Ion Exchange

- Used for removal of **inorganics consists**

- passing the water successively over a **solid cation exchanger** and **a solid anion exchanger**

    - which replace cations and anions by **hydrogen ion** and **hydroxide ion**, respectively,

- The cation exchanger is regenerated with strong acid and the anion exchanger with strong base.

where : hypothetical **ionic salt MX**

: -{Cat(s)} represents the solid cation exchanger

:+{An(s)} represents the solid anion exchanger.

- $H^+\text{-}\{Cat(s)\} + M^+ + X^- \text{ ------ } M^+\text{-}\{Cat(s)\} + H^+ + X^-$
- $OH^-\text{+}\{An(s)\} + H^+ + X^-\text{------ } X^-\text{+}\{An(s)\} + H_2O$
- Nitrate can be removed by anion exchange.

Effect ion exchange:-

Parameter	Raw water	product
NO^-_3	50 mg/l	2 mg/l
Cl^-	23 "	87 mg/l
$SO_4^=$	18 "	1 "
HCO^-_3	2.9 mmol/l	2.6 mmol/l
PH	7.2	7.2

Disadvantages
-Costs
-Discharge regenerate

UNIT FIVE

Water transmission and distribution

Water transmission

- The water needs to be transported from the **source** to the **treatment plant**, and onward to the **area of distribution**.

- Depending on the **topography and local conditions** the water may be conveyed through:
  - Free-flow conduits
  - Closed conduits
  - A combination of both

– The water conveyance will be either under **gravity** or **by pumping.**

- **Free-flow conduits** are generally **laid at a uniform slope** that closely follows the hydraulic grade line.
  - Ex.: canals, partially filled pipes
  - **limited application in water supply** practice
    - danger that the water will **get contaminated**
    - **never appropriate for treated water**
    - used for **transmission of raw water**

- **Closed conduit flows**, also commonly called **pressurized flows,** apply in this case**.**
  - can be **laid up-and downhill as needed**, as long as they remain at sufficient distance below the hydraulic grade line

Types of water conduits

1. **Canals - ** are laid in areas where the **required slope** of the conduit more or less coincides with the **slope of the terrain**.

2. **Tunnels -** are constructed in **hilly areas**.
   - **Size** that they are approximately **three-quarters full at the design flow rate**.
   - Use to **shorten the overall length of a water transmission** route

3. Free-flow pipelines

- transport of **smaller quantities of water than tunnels**.
- **Offer better protection** from pollution.
- Due to the free-flow conditions, **simple materials may be used** for construction. Eg. **clay**

4. Pressurised pipelines :

- much less limited by the **topography of the area** to be traversed, than is the case of canals, aqueducts or free-flow pipelines.
- A pressure pipeline may **run up-and downhill**

Design parameters for water transmission

1. Design flow

- The **transmission main** is normally designed for the **carrying capacity needed to supply** **water demand** on the maximum consumption day at a constant rate.

- **Hourly variations** to be evened out by the **service reservoir**

- The **number of hours the transmission main operates** each day is another important factor.

  - Diesel engine or electric motor-driven pumps, the daily pumping often is limited **to 16 hours or less**.
    - In such a case, **the design flow rate for the transmission** main as well as the volume of the service reservoir need to be adjusted accordingly.

2. Design pressure

- Only relevant for **pressurized pipelines**
- Consumer connections on transmission lines are rare, so the **water pressure can be kept low**
  - –Provided that the **hydraulic grade line is positioned above the pipe** :
    - Over its **entire length** and
    - For all flow rates.

- A minimum of a **few meters water column is also required**
  - **to prevent intrusion** of pollution through damaged parts of the pipe or faulty joints.

- Operating pressure in the pipeline **be less than 4-5 mwc (metres water column).**

- High pressures **can be avoided** in this case by application of **multistage pumping along the pipe route**.

3. Design velocity and hydraulic gradient

- **A velocity range** is established for design purposes **for two reasons**.

  1. Minimum velocity will be required to **prevent water stagnation causing sedimentation and bacteriological growth in the conduits**.

  2. Maximum velocity will have to be respected in order **to control head losses** in the system as well as **to reduce the effects of water hammer**.

- **The velocity of flows in canals and tunnels usually**
  - Between **0.4 and 1.0 m/s** for unlined conduits
  - **2 m/s for lined conduits.**
- Flows in pressurized transmission mains have the velocity range between 1 and 2 m/s.
- In the case of pressurized pipes, **design values may also be set for the hydraulic gradient**.
  - **to limit the head losses**
    - i.e. to minimize the. **energy consumption for pumping the water**

- Common values of the hydraulic gradients for transmission pipes are **around 0.005**,
    - which means **5 mwc of head loss per km of the pipe length**

Water distribution

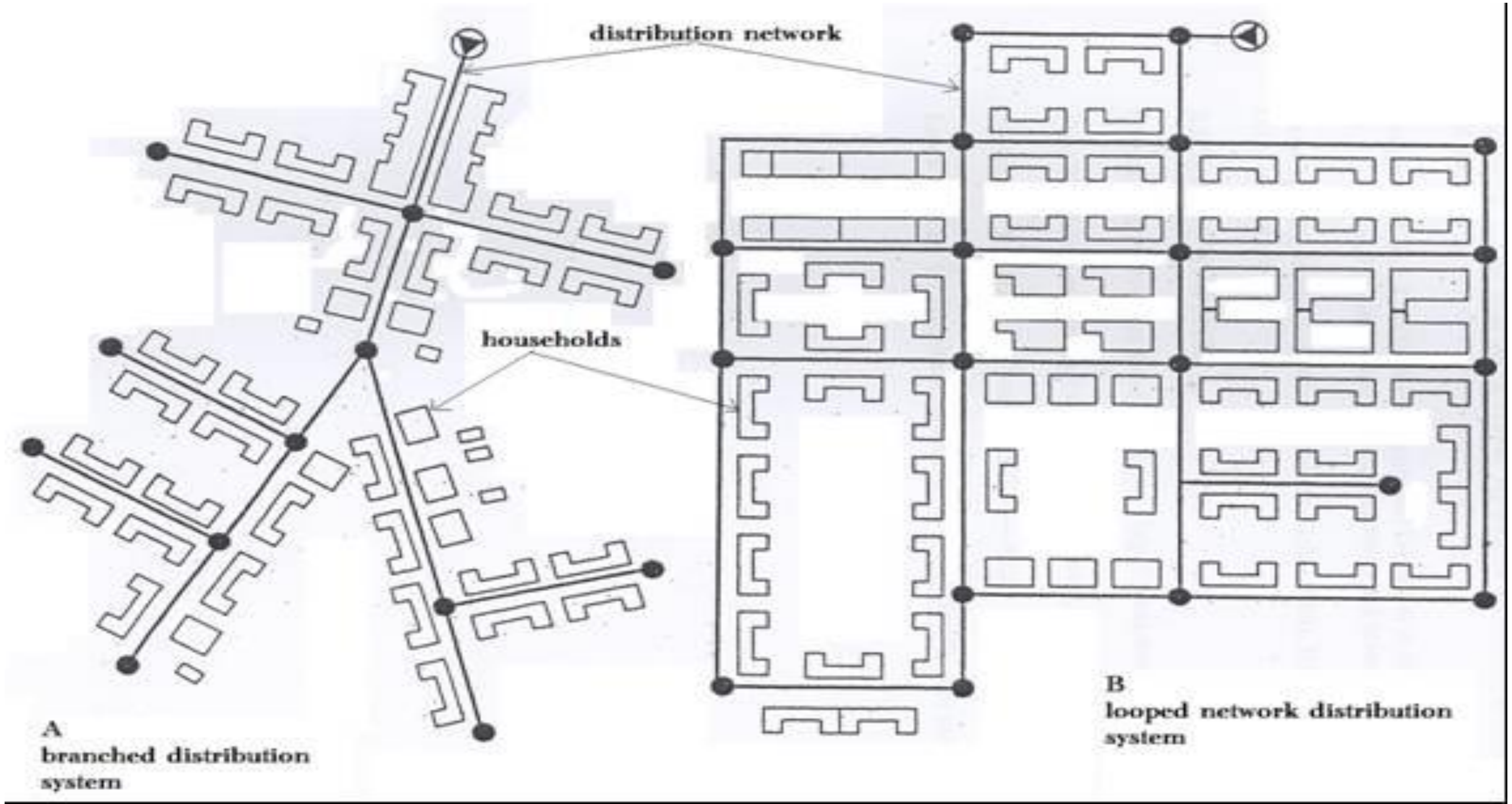
Water distribution systems **convey water drawn** from the water source of treatment facility/reservior, **to the point where it is delivered to the users**

- these systems **deal with water a demand** that varies considerably in the course of a day.
  - **Consumption is highest** during the hours that water is used for **personal hygiene and cleaning, when food preparation and clothes washing are done.**
  - **Water use is lowest during night**
- variation in flow can be dealt with **by operating pumps**
- For **small community** water supplies: **a service reservoir is the preferable option**

Types of distribution systems

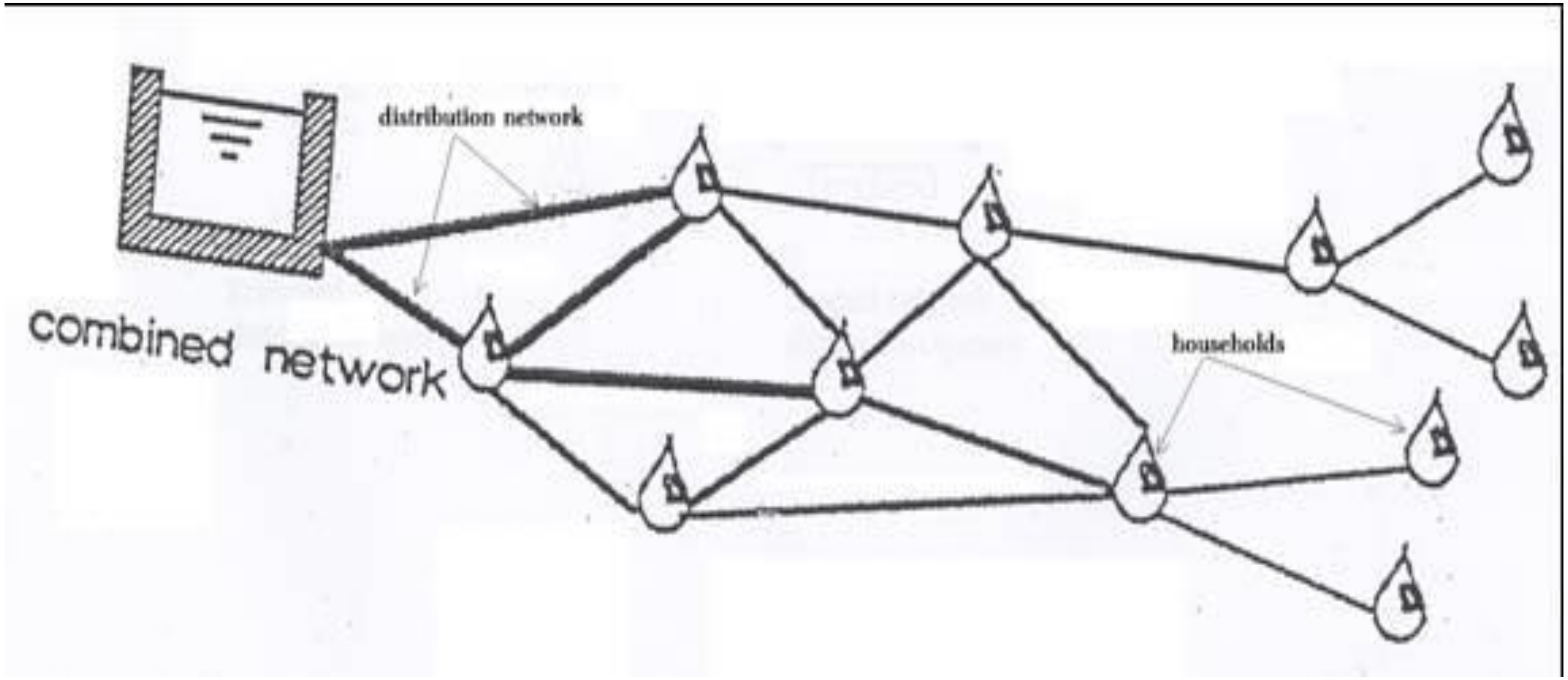
There are basically **two main layouts** of a distribution network:

1. Branched configuration
2. Looped (or "grid") configuration



- **Branched networks:** have **simplicity and acceptable investment costs**, but some **disadvantages**:
  - Low reliability, which affects all users located downstream of any **breakdown in the system**.
  - Danger of contamination caused by the possibility that a **large part of network will be without water** during irregular situations.
  - **Accumulation of sediments**, due to stagnation of the water at the system ends (‘**dead’ ends**) occasionally resulting in **taste and odour problems**.
  - Fluctuating water demand producing rather **large pressure variations.**

- The network in **large (urban) distribution systems** will be much more complex; essentially a **combination of loops and branches** with lots of interconnected pipes that requires many valves and special parts.



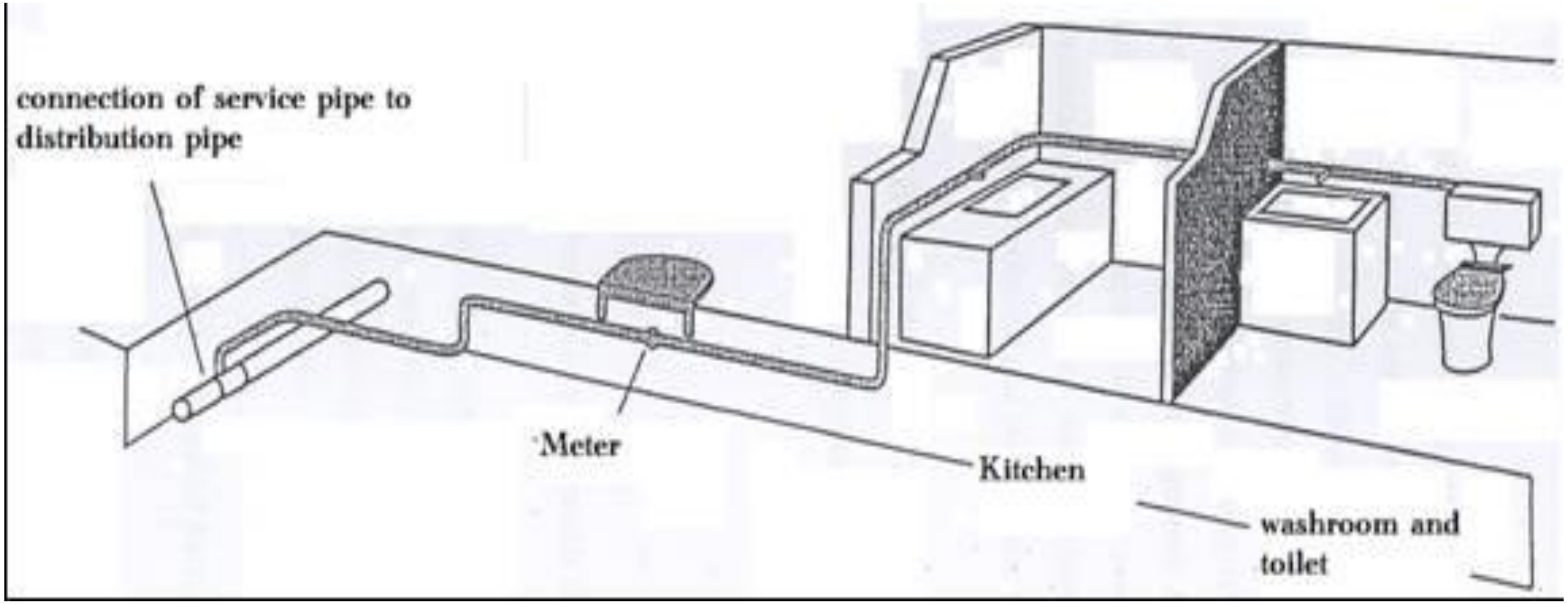
Service connections

- Points at which the **water delivered to the users**

- The following types of service connections may be distinguished:

    - **House connection**
    - **Yard connection**
    - **Group connection**
    - **Public standpipe**

House connection

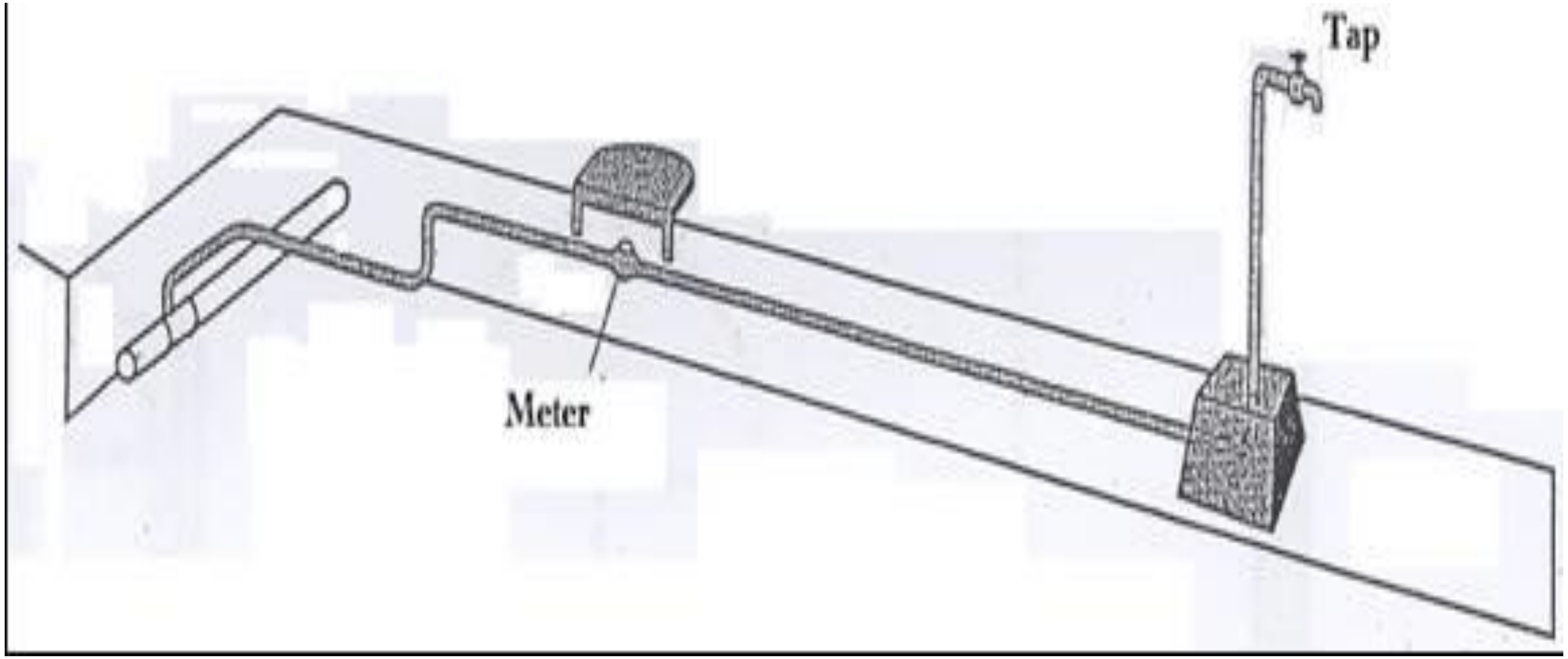


- water service pipe connected with in-house
- The service pipe is connected to the distribution main in the street

Yard connection

- A yard connection is quite **similar to a house connection**, the only difference being that the **tap is placed in the yard outside the house**.

- **No in-house piping and fixtures are provided**



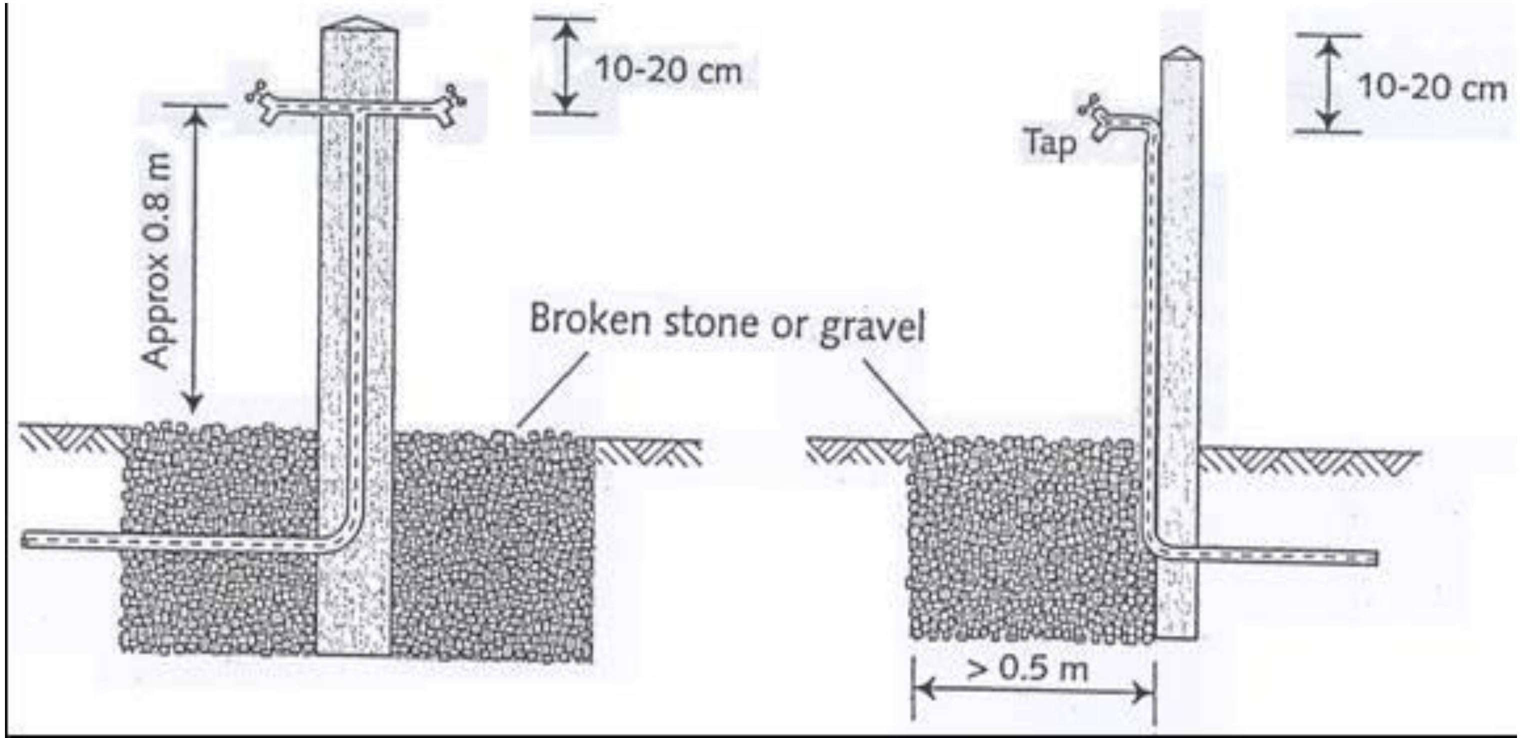
Group connection

- **Outside tap** that are shared by a **clearly defined group of households**, often neighbors.

- They share the tap and pay the bill together
- Each family may **pay the same** (flat) share **or** contributions may be **weighed according to the estimated volume** of water each family consumes
  - **Consumption estimates….** family size
  - Sometimes the taps can be locked and a local committee holds the key and manages the use and financing

Public standpipe

- Can have **one or more taps**.
- **Single-tap and double-tap standpipes** are the most common types in rural areas.
- They are made or **brickwork, masonry or concrete**, or use wooden poles and similar materials.



Thanks!